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Do Matching Frictions Explain Unemployment? Not in Bad Times

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Abstract
This paper models unemployment as the result of matching frictions and job rationing. Job rationing is a shortage of jobs arising naturally in an economic equilibrium from the combination of some wage rigidity and diminishing marginal returns to labor. During recessions, job rationing is acute, driving the rise in unemployment, whereas matching frictions contribute little to unemployment. Intuitively, in recessions jobs are lacking, the labor market is slack, recruiting is easy and inexpensive, so matching frictions do not matter much. In a calibrated model, cyclical fluctuations in the composition of unemployment are quantitatively large.

Keywords: Unemployment; matching frictions; job rationing
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1 Introduction

Unemployment spikes frequently across the U.S. and Europe, most recently in 2008–2010, and remains a major concern for policymakers. To determine optimal policy responses, it is critical to identify the main sources of unemployment. I propose a framework that accommodates two important sources of unemployment: (i) job rationing, which is a shortage of jobs in the economy; and (ii) matching frictions, which make it costly for recruiting firms to match with unemployed workers. I study how these two sources interact over the business cycle to shed new light on the mechanics of unemployment fluctuations.

This paper develops a tractable model that distinguishes between two components of unemployment: (i) *rationing unemployment*, which measures the shortage of jobs in the economy, irrespective of matching frictions; and (ii) *frictional unemployment*, which measures additional unemployment attributable to matching frictions. Formally, I define rationing unemployment as the amount of unemployment that would prevail if recruiting cost was zero, and frictional unemployment as additional unemployment due to a positive recruiting cost. The paper makes four contributions to our understanding of unemployment fluctuations. First, it proposes conditions under which rationing unemployment is positive. Second, it proves theoretically that during a recession rationing unemployment increases, driving the rise in total unemployment, while frictional unemployment decreases. Third, it shows that even a small amount of wage rigidity, such as that estimated with microdata on earnings of newly hired workers, is sufficient to amplify technology shocks as much as in the data. Hence, moments of key labor market variables simulated with the calibrated model match those estimated in U.S. data well. Fourth, the paper finds that cyclical fluctuations in the composition of unemployment are quantitatively large: when unemployment is below 5 percent, it is all frictional; but when unemployment reaches 8 percent, frictional unemployment amounts to less than 2 percent of the labor force, and rationing unemployment to more than 6 percent.

The model departs from the literature by allowing for job rationing, a shortage of jobs resulting from a failure of the labor market to clear even in the absence of matching frictions. Even if recruiting cost is zero, workers may not all be profitably employed and some unemployment, which

I call *rationing unemployment*, may remain. Since recruiting cost is actually positive, total unemployment is higher than rationing unemployment, and the difference between the two is *frictional unemployment*.

There is no job rationing in existing search-and-matching models because they assume that there would not be any unemployment without a positive recruiting cost. In the canonical search-and-matching model, wages are the outcome of Nash bargaining and by construction always remain below the marginal product of labor (Hagedorn and Manovskii 2008; Mortensen and Pissarides 1994; Pissarides 2000; Shimer 2005). Therefore if recruitment cost falls to zero, firms make a positive profit on each new match and will enter the labor market until there is full employment. By the same logic, there is full employment in the absence of recruiting costs in models using different bargaining procedures (Cahuc et al. 2008; Elsby and Michaels 2008; Hall and Milgrom 2008; Rotemberg 2008). Shimer (2004) and Hall (2005a) introduce wage rigidity into search-and-matching models, in the form of a constant real wage. But since these models assume atomistic firms for simplicity, the marginal product of labor is independent of aggregate employment. Thus if productivity is above the constant wage and recruitment cost falls to zero, firms enter until there is full employment. Job rationing is absent from these atomistic-firm models with rigid wages, and likewise from large-firm models with wage rigidity and either constant marginal returns to labor in production, or diminishing marginal returns to labor and instantaneous capital adjustment (Blanchard and Galí 2010; Gertler and Trigari 2009).

To provide a more general framework in which unemployment may arise from both matching frictions and job rationing, this paper builds on the Pissarides (2000) model by relaxing two of its key assumptions: completely flexible wages and constant marginal returns to labor. These assumptions are critical because *either* implies that there would not be any unemployment without a positive recruiting cost. Specifically, I develop a dynamic stochastic general equilibrium model in which large firms face a labor market with matching frictions, as in Blanchard and Galí (2010). All household members are in the labor force at all times, either working or searching for a job. Firms open vacancies to hire new workers each period in response to exogenous job destruction and technology shocks. Recruiting is costly because of matching frictions, especially in expansions when firms post many vacancies that are filled from a small pool of unemployed workers. I assume that firms face diminishing marginal returns to labor in production. I introduce rigid wages, which do not adjust as much as technology. In a frictional labor market, rigid wages are a possible equilibrium outcome. Even if wages are rigid, they may remain in the interval between the flow value of unemployment and the marginal product of labor, and neither interfere with the efficient formation of worker-firm matches nor cause inefficient match destructions. In that case, wages satisfy the equilibrium requirement that worker-firm pairs exploit all the bilateral gains from trade (Hall 2005a).

Assuming diminishing marginal returns to labor and wage rigidity is appealing for several reasons. First, both assumptions have been used (but not combined) in the search-and-matching literature, and are standard in the broader macroeconomic literature.[1] Second, both are empirically relevant. At business cycle frequency, some production inputs are slow to adjust and the short-run production function is likely to exhibit diminishing marginal returns to labor. Substantial ethnographic and empirical literatures also document wage rigidity.[2] Third, job rationing can be readily quantified, because diminishing marginal returns to labor can be calibrated using aggregate data on the labor share, and the response of wages to technology shocks has been estimated with microdata on individual wages.

The fundamental property of this model is that there may be some unemployment even in the absence of matching frictions. To understand why jobs may be rationed, I first abstract from recruiting expenses. Since there is perfect competition in the goods market, firms hire workers until marginal product of labor equals wage. The marginal product of labor decreases with employment because of diminishing marginal returns. In response to a negative technology shock, the marginal product of labor falls whereas rigid wages adjust downwards only partially. If the shock is suffi-

[1] There is a long tradition of macroeconomic models featuring a short-run production function with labor as the only variable input, and with diminishing marginal returns to labor (for example, Benigno and Woodford 2003). Wage rigidity features in the many dynamic stochastic general equilibrium models that use the Taylor (1979) and Calvo (1983) staggered wage-setting mechanisms, and Christiano et al. (2005) argue that wage rigidity is important for improving realism in this class of models.

[2] Blinder and Choi (1990), Campbell and Kamlani (1997) and Bewley (1999) provide ethnographic evidence. Kramarz (2001) surveys studies based on wage microdata. Dickens et al. (2007) provide recent evidence from European wage microdata.

ciently large, the marginal product of labor of the last workers in the labor force may fall below the wage. It becomes unprofitable for firms to hire these workers. Some unemployment, which I call rationing unemployment, would prevail even if recruiting cost was nil. With a positive recruiting cost, the marginal cost of labor is higher and firms reduce employment. The resulting amount of additional unemployment is frictional unemployment.

In recessions marginal profitability falls further and job rationing is more acute. Rationing unemployment increases, driving the rise in total unemployment. Many unemployed workers apply to the few vacancies left. Each vacancy is filled rapidly and at a low cost in spite of matching frictions. Since recruiting expenses barely raise the marginal cost of labor, profit-maximizing firms barely reduce employment compared to the level prevailing in the absence of recruiting costs. Therefore, frictional unemployment is lower in recessions than in normal times. To summarize, in expansions, matching frictions explain all of unemployment. In recessions, falling technology leads to an acute shortage of jobs that drives an increase in total unemployment; simultaneously, the amount of additional unemployment attributable to matching frictions falls because it becomes easier for firms to recruit.

I commence the analysis with a theoretical study of the comovements of unemployment and its components using comparative statics with respect to technology. I opt to work in a model without aggregate uncertainty because it has the same qualitative behavior as the fully dynamic model, in spite of the dynamic nature of firms' decisions and the dynamic adjustment process of unemployment. Moreover its equilibrium can be studied analytically and represented diagrammatically. Next, I use numerical methods to quantify frictional and rationing unemployment in a stochastic environment that accounts fully for rational expectations of firms as well as the law of motion of unemployment.

I calibrate the model with U.S. data and simulate the impact of technology shocks. Simulated moments for labor market variables are close to their empirical counterparts. Critically, even a high estimate of wage flexibility, such as that obtained by Haefke et al. (2008) using microdata on earnings of new hires, is sufficient for the model to amplify technology as much as in the data. I construct a historical time series for unemployment by simulating the model with the technology series measured in U.S. data over the 1964–2009 period. Model-generated unemployment and actual unemployment match closely. The model fits the data well despite its simplicity, lending support to the quantitative analysis that follows.

I decompose model-generated unemployment into historical time series for frictional and rationing unemployment. This simulation uncovers quantitatively large cyclical fluctuations in frictional and rationing unemployment. In the model, as long as total unemployment is below 4.8 percent, it can all be attributed to matching frictions. On average, total unemployment amounts to 5.8 percent of the labor force, frictional unemployment to 3.6 percent, and rationing unemployment to 2.2 percent. But in deep recessions, when total unemployment reaches 8.0 percent, rationing unemployment increases above 6.0 percent, while frictional unemployment decreases below 2.0 percent.

The paper is organized as follows. Section 2 presents the general model on which my analysis rests. Section 3 frames several influential search-and-matching models as special cases of the general model to show that they do not have job rationing. Section 4 theoretically studies unemployment and its components in a specific model in which job rationing arises from wage rigidity and diminishing marginal returns to labor. Section 5 calibrates this specific model to quantify fluctuations in rationing and frictional unemployment. Section 6 discusses normative implications and relates this work to the macroeconomic literature on unemployment. All proofs are in the Appendix.

2 General Model

This is a discrete-time model. Fluctuations are driven by technology, which follows a Markov process $\{a_t\}_{t=0}^{+\infty}$.[3]

[3]This model takes the view that recessions are driven by aggregate-activity shocks and not by reallocation shocks, in line with empirical evidence (Abraham and Katz 1986; Blanchard and Diamond 1989; Hall 2005b). Thus I assume a stable matching function and, following the literature, I introduce aggregate technology shocks.

2.1 Household

The representative household is composed of a mass 1 of infinitely-lived workers. It has risk-neutral von Neumann-Morgenstern preferences over consumption, and it discounts future payoffs by a factor $\delta \in (0,1)$. It consumes all its income each period: $C_t = W_t \cdot N_t + \pi_t$, where C_t is consumption, W_t is the average real wage, and π_t is the aggregate real profit of firms, which are owned by the household.[4]

2.2 Labor market

A continuum of firms indexed by $i \in [0,1]$ hire workers. At the end of period $t-1$, a fraction s of the N_{t-1} existing worker-job matches are exogenously destroyed. Workers who lose their job can apply for a new job immediately. At the beginning of period t, U_{t-1} unemployed workers are looking for a job:

$$U_{t-1} = 1 - (1-s) \cdot N_{t-1}. \tag{1}$$

At the beginning of period t, firms open V_t vacancies to recruit unemployed workers. The number of matches made in period t is given by a constant-returns matching function $h(U_{t-1}, V_t)$, differentiable and increasing in both arguments. Conditions on the labor market are summarized by the labor market tightness $\theta_t \equiv V_t/U_{t-1}$. An unemployed worker finds a job with probability $f(\theta_t) \equiv h(U_{t-1}, V_t)/U_{t-1} = h(1, \theta_t)$, and a vacancy is filled with probability $q(\theta_t) \equiv h(U_{t-1}, V_t)/V_t = h(1/\theta_t, 1) = f(\theta_t)/\theta_t$. In a tight market it is easy for jobseekers to find jobs—the job-finding probability $f(\theta_t)$ is high—and difficult for firms to hire workers—the job-filling probability $q(\theta_t)$ is low. Keeping a vacancy open has a per-period cost of $c \cdot a_t$ units of consumption. The recruiting cost $c \in (0, +\infty)$ captures the resources that firms must spend to recruit workers because of matching frictions. I assume no randomness at the firm level: a firm fills a job with certainty by opening $1/q(\theta_t)$ vacancies. Thus, a firm spends $c \cdot a_t/q(\theta_t)$ to fill a job. When the labor market is tighter, a vacancy is less likely to be filled, a firm must post more vacancies to fill a vacant job, and

[4] There is no labor-supply decision (neither number of hours nor labor market participation). This setup is standard in the literature. It is motivated by empirical work on the cyclical behavior of the labor market that suggests that hours per worker and labor force participation are quite acyclical (Shimer 2010).

recruiting is more costly.

Firm i decides the number $H_t(i) \geq 0$ of workers to hire at the beginning of period t. The aggregate number of recruits is $H_t = \int_0^1 H_t(i)di$. Number of hires H_t, labor market tightness θ_t, and unemployment U_{t-1} are related by the job-finding probability:

$$f(\theta_t) = \frac{H_t}{U_{t-1}}. \tag{2}$$

Upon hiring, $N_t(i) = (1-s) \cdot N_{t-1}(i) + H_t(i)$ workers are employed in firm i. The aggregate number of employed workers is $N_t = \int_0^1 N_t(i)di$. When the labor market is in steady state, labor market tightness θ is related to employment N by an upward-sloping Beveridge curve that captures the equality of flows into and out of unemployment:

$$N = \frac{1}{(1-s) + s/f(\theta)}. \tag{3}$$

2.3 Wage schedule

The wage is set once a worker and a firm have matched. The marginal product of labor always exceeds the flow value of unemployment, which is normalized to zero, so there are always mutual gains from matching. There is no compelling theory of wage determination in such an environment (Hall 2005a; Shimer 2005). Hence, I consider in the next sections a broad set of wage-setting mechanisms: generalized Nash bargaining; Stole and Zwiebel (1996) intra-firm bargaining; and various reduced-form rigid wages. For now, I use a general wage schedule, which does not result from a specific wage-setting mechanism but nests as special cases the schedules studied later:

$$W_t(i) = W(N_t(i), \theta_t, N_t, a_t), \tag{4}$$

where $W_t(i)$ is the wage paid by firm i to all its workers at time t. $W(.)$ is continuous and differentiable in all arguments. This schedule has a natural interpretation. Since technology a_t and employment $N_t(i)$ determine current marginal productivity in the firm, they affect wages paid to workers. Labor market tightness in the current period θ_t determines outside opportunities of firms and workers, and also affects wages. Finally in a symmetric environment, because of the Markov property of the stochastic process for technology, aggregate employment N_t and technology fully determine the state of the economy and summarize the information set at time t; thus, conditional expectations as of time t are measurable with respect to (N_t, a_t). In so far as expectations about future economic outcomes affect wages, N_t and a_t affect wages.

2.4 Firms

Firms produce a homogeneous good sold on a perfectly competitive market. Firms take prices as given and I can normalize the price of the good to 1 in each period. A firm's expected sum of discounted real profits is

$$\mathbb{E}_0\left[\sum_{t=0}^{+\infty}\delta^t\cdot\pi_t(i)\right], \tag{5}$$

where $\pi_t(i)$ is the real profit of firm i in period t:

$$\pi_t(i) = F(N_t(i), a_t) - W_t(i)\cdot N_t(i) - \frac{c\cdot a_t}{q(\theta_t)}\cdot H_t(i).$$

The production function $F(\cdot,\cdot)$ is differentiable and increasing in both arguments. The aggregate real profit is $\pi_t = \int_0^1 \pi_t(i)di$. The firm faces a constraint on the number of workers employed each period:

$$N_t(i) \leq (1-s)\cdot N_{t-1}(i) + H_t(i). \tag{6}$$

DEFINITION 1 (Firm problem)**.** Taking as given the wage schedule (4), as well as labor market tightness, aggregate employment, and technology $\{\theta_t, N_t, a_t\}_{t=0}^{+\infty}$, the firm chooses stochastic processes $\{H_t(i), N_t(i)\}_{t=0}^{+\infty}$ to maximize (5) subject to the sequence of recruitment constraints (6). The time t element of a firm's choice must be measurable with respect to (a^t, N_{-1}) where $a^t \equiv (a_0, a_1, \ldots, a_t)$.

I assume that the firm maximization problem is concave for any recruiting cost $c \in (0, +\infty)$. The unique solution to the firm problem is characterized by two equations. First, employment $N_t(i)$ and number of hires $H_t(i)$ are related by

$$H_t(i) = N_t(i) - (1-s) \cdot N_{t-1}(i)$$

because endogenous layoffs never occur in equilibrium. Second, employment $N_t(i)$ is determined by the following first-order condition, which holds with equality if $N_t(i) < 1$:

$$\frac{\partial F}{\partial N}(N_t(i), a_t) \geq W_t(i) + \frac{c \cdot a_t}{q(\theta_t)} + N_t(i) \frac{\partial W}{\partial N}(N_t(i), \theta_t, N_t, a_t) - \delta(1-s)\mathbb{E}_t \left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})}\right] \tag{7}$$

This Euler equation implies that firm i hires labor until marginal revenue from hiring equals marginal cost. The marginal revenue is the marginal product of labor $\partial F/\partial N$. The marginal cost is the sum of the wage $W_t(i)$, the cost of hiring a worker $c \cdot a_t/q(\theta_t)$, the change in the wage bill from increasing employment marginally $N_t(i) \cdot \partial W/\partial N$, minus the discounted cost of hiring next period $\delta \cdot (1-s) \cdot \mathbb{E}_t [c \cdot a_{t+1}/q(\theta_{t+1})]$.

2.5 Equilibrium

DEFINITION 2 (Symmetric equilibrium)**.** Given initial employment N_{-1} and a stochastic process $\{a_t\}_{t=0}^{+\infty}$ for technology, a symmetric equilibrium is a collection of stochastic processes

$$\{C_t, Y_t, N_t, H_t, \theta_t, U_t, W_t\}_{t=0}^{+\infty}$$

that solve the household and firm problems, satisfy the law of motion for unemployment (1), the law of motion for labor market tightness (2), the wage schedule (4), and the resource constraint in the economy, which imposes that all production is either consumed or allocated to recruiting:

$$Y_t \equiv \int_0^1 F(N_t(i), a_t) di = C_t + \frac{c \cdot a_t}{q(\theta_t)} \cdot H_t.$$

Moreover, the wage $\{W_t\}_{t=0}^{+\infty}$ satisfies the condition that no worker-employer pair has an unexploited opportunity for mutual improvement. The wage should neither interfere with the formation of an employment match that generates a positive bilateral surplus, nor cause the destruction of such a match .

The equilibrium definition imposes that neither workers nor firms decide to break existing matches since any match generates some surplus.[5] Since workers would never quit, the definition restricts wages to remain low enough in response to adverse technology shocks to avoid inefficient separations. As in Hall (2005a), the equilibrium of the model avoids the criticism directed at sticky-wage models by Barro (1977) because it satisfies the criterion that no employer-worker pair forgoes opportunities for bilateral improvement. In Sections 3 and 4 , I characterize and analyze equilibria for various specifications of the production function and the wage schedule. I aim to determine whether jobs are rationed in these equilibria. But before proceeding, I define job rationing.

2.6 Job rationing

Consider a counterfactual environment in which matching frictions are absent. The matching process remains the same: firms open vacancies; firms and workers match; and the worker-firm pair either settles on a wage or dissolves the match. The matching technology characterized by the matching function $h(U,V)$ remains the same. However, firms do not need to devote any resources (time or material) to recruiting because there are no matching frictions: the recruiting cost c converges to 0. When jobs are rationed, some unemployment remains in equilibrium. In other words, the economy does not converge to full employment even in the absence of matching frictions.

My study of job rationing focuses on static environments without aggregate shocks ($a_t = a$ for all $t \geq 0$) and with a labor market in steady state (equation (3) holds). This approach has three major advantages. First, I can analytically study the equilibrium and perform comparative statics to understand comovements of technology and labor market variables.[6] Second, I can represent the equilibrium diagrammatically to provide an intuitive understanding of the mechanics of the model.

[5]The only separations observed in equilibrium are periodic, exogenous destructions of a fraction s of all jobs.

[6]The comparative-static approach is commonly used to understand theoretical properties of search models of the labor market (Hagedorn and Manovskii 2008; Mortensen and Nagypál 2007; Shimer 2005).

Third, the static model delivers the same qualitative predictions as a fully dynamic model.[7]

3 The Absence of Job Rationing in Existing Search-and-Matching Models

I specialize the model presented in Section 2 to three influential search-and-matching models: the canonical search-and-matching model, its variant with diminishing marginal returns to labor in production, and its variant with rigid wages. I demonstrate that job rationing is absent from these models: the economy converges to full employment when recruiting cost c converge to 0. Hence, existing models consider that matching frictions are the sole source of unemployment and that eliminating frictions would eliminate unemployment. This underlying assumption strongly influences the welfare implications and policy recommendations derived from these models.

3.1 Mortensen-Pissarides model (MP model)

ASSUMPTION 1 (Constant returns to labor)**.** $F(N,a) = a \cdot N$.

ASSUMPTION 2. There exists $\beta \in (0,1)$ such that

$$W(N_t(i), \theta_t, N_t, a_t) = \frac{c \cdot \beta}{1-\beta} \cdot \left\{ \frac{a_t}{q(\theta_t)} + \delta \cdot (1-s) \cdot \mathbb{E}_t \left[a_{t+1} \cdot \left(\theta_{t+1} - \frac{1}{q(\theta_{t+1})} \right) \right] \right\}.$$

The MP model, characterized by Assumptions 1 and 2, retains the key elements of the canonical search-and-matching model studied in Pissarides (2000) and Shimer (2005). Lemma 1 shows that the wage schedule specified by Assumption 2 corresponds to the generalized Nash bargaining

[7] In some of the specifications presented below, labor market tightness in the stochastic environment is invariant to technology, and solves the same equation as labor market tightness in any static environment. In other specifications, the equilibrium of the static model approximates the equilibrium of the fully dynamic model well, with the same qualitative properties. This approximation is valid for two reasons: (i) the labor market rapidly converges to an equilibrium in which inflows to and outflows from employment are balanced because rates of job destruction and job creation are large (Hall 2005a; Pissarides 2009; Rotemberg 2008); at the same time (ii) the recruiting behavior of firms is scarcely altered when they expect future shocks because technology is quite autocorrelated and shocks are of small amplitude.

solution, which allocates a fraction $\beta \in (0,1)$ of the surplus of a match to the worker, and the rest to the firm.

LEMMA 1 (Equivalence with Nash bargaining)**.** *Let $W(\cdot)$ be specified in Assumption 2. Assume that $W_t(i)$ in any period t in any firm i is determined by generalized Nash bargaining, and β is workers' bargaining power. Then $W_t(i) = W(N_t(i), \theta_t, N_t, a_t)$.*

In the symmetric equilibrium of the MP model, the Euler equation (7) becomes

$$(1-\beta) \cdot a_t = \frac{c \cdot a_t}{q(\theta_t)} + c \cdot \delta \cdot (1-s) \cdot \mathbb{E}_t \left[a_{t+1} \cdot \left(\beta \cdot \theta_{t+1} - \frac{1}{q(\theta_{t+1})} \right) \right].$$

I assume that technology follows a martingale: for all $t \geq 0$, $\mathbb{E}_t[a_{t+1}] = a_t$. Then equilibrium labor market tightness is invariant to technology shocks, because the marginal recruiting costs, the wage, and the marginal product of labor increase in the same proportion as technology. Hence, θ is constant and determined by[8]

$$(1-\beta) = c \cdot \left[\frac{1-\delta \cdot (1-s)}{q(\theta)} + \delta \cdot (1-s) \cdot \beta \cdot \theta \right]. \tag{8}$$

Equation (8) also characterizes equilibrium labor market tightness in a static environment for any technology level a. Since labor market tightness is identical in any static or stochastic environment, I focus on a static environment. Equations (3) and (8) uniquely define equilibrium employment and labor market tightness as implicit functions $N(c)$ and $\theta(c)$ of recruiting cost c. Proposition 1 shows that jobs are not rationed in the MP model because the economy converges to full employment when matching frictions vanish.

PROPOSITION 1 (Full employment in MP model)**.** *Under Assumptions 1 and 2, for any technology $a \in (0, +\infty)$, $\lim_{c \to 0} \theta(c) = +\infty$ and $\lim_{c \to 0} N(c) = 1$.*

A simple diagram in Figure 1 explains this result. Expressing labor market tightness θ as a function of employment N, I represent equilibrium condition (8) on a plane with employment

[8] Even though the setup is slightly different, the equilibrium condition is similar to that derived in Pissarides (2000) for the canonical model when the flow value of unemployment is zero.

on the x-axis. The horizontal line is the marginal profit from hiring labor gross of recruiting expenses, on the left-hand side of (8).[9] By construction, gross marginal profit is independent of labor market tightness θ and recruiting cost c. Here, the gross marginal profit is simply the marginal product of labor. The upward-sloping line is marginal recruiting expenses, on the right-hand side of (8). These expenses are imposed by the presence of a positive recruiting cost c, directly through the opening of vacancies, and indirectly through wage bargaining. The intersection of these two curves determines equilibrium unemployment. As illustrated in Figure 1, when the recruiting cost decreases, the marginal-recruiting-expense curve shifts down while the gross-marginal-profit curve is unchanged. Hence equilibrium employment increases. When recruiting cost c converges to 0, employment N converges to 1: there is full employment.

This result can also be interpreted from the perspective of bilateral bargaining theory. Broadly speaking, the difference between the marginal product of labor and the flow value of unemployment is proportional to the bilateral surplus from a match. Hence the surplus is positive and independent from aggregate employment. Once recruiting expenses are sunk, any match generates the same positive surplus that is shared between firm and worker by Nash bargaining over wages. When recruiting cost c converges to 0, recruiting a worker is costless; thus, the net profit from any new match is positive and firms open vacancies to create jobs until all workers are employed.

3.2 Large-firm model with Stole-Zwiebel intra-firm bargaining (SZ Model)

ASSUMPTION 3 (Diminishing marginal returns to labor)**.** $F(N,a) = a \cdot N^{\alpha}$, $\alpha \in [0,1)$.

ASSUMPTION 4. There exists $\beta \in (0,1)$ such that

$$W(N_t(i), \theta_t, N_t, a_t) = \frac{\alpha \cdot \beta}{1 - \beta \cdot (1-\alpha)} \cdot a_t \cdot N_t(i)^{\alpha - 1} + c \cdot (1-s) \cdot \delta \cdot \beta \cdot \mathbb{E}_t \left[a_{t+1} \cdot \theta_{t+1} \right].$$

The SZ model, characterized by Assumptions 3 and 4, retains the key elements of the large-firm search-and-matching models with diminishing marginal returns to labor and the Stole and Zwiebel

[9] Both sides of the equation have been normalized by $a/(1-\beta)$. In the next sections, I normalize other equilibrium conditions by technology a.

(1996) intra-firm bargaining procedure studied in Cahuc et al. (2008) and Elsby and Michaels (2008). The main departure from the MP model is introducing diminishing marginal returns to labor, which requires the bargaining procedure to be adapted. Lemma 2 shows that the wage schedule specified by Assumption 4 corresponds to the Stole and Zwiebel (1996) bargaining solution, which allocates a fraction $\beta \in (0,1)$ of the marginal surplus to workers, and the rest to the firm.

LEMMA 2 (Equivalence with Stole and Zwiebel (1996) bargaining)**.** *Let $W(\cdot)$ be specified in Assumption 4. Assume that the wage $W_t(i)$ in any period t in any firm i is determined by Stole and Zwiebel (1996) bargaining, and β is workers' bargaining power. Then $W_t(i) = W(N_t(i), \theta_t, N_t, a_t)$.*

In the symmetric equilibrium of the SZ model, the Euler equation (7) becomes

$$\left[\frac{1-\beta}{1-\beta\cdot(1-\alpha)}\right] a_t \cdot \alpha \cdot N_t^{\alpha-1} = \frac{c\cdot a_t}{q(\theta_t)} + c\cdot\delta\cdot(1-s)\cdot\mathbb{E}_t\left[a_{t+1}\cdot\left(\beta\cdot\theta_{t+1} - \frac{1}{q(\theta_t+1)}\right)\right].$$

As in the MP model, if technology follows a martingale, equilibrium labor market tightness θ is invariant to technology shocks. It is related to equilibrium employment N through the same equation that links them in a static environment:[10]

$$\left[\frac{1-\beta}{1-\beta\cdot(1-\alpha)}\right]\alpha\cdot N^{\alpha-1} = c\cdot\left[\frac{1-\delta\cdot(1-s)}{q(\theta)} + \delta\cdot(1-s)\cdot\beta\cdot\theta\right] \tag{9}$$

Equations (3) and (9) implicitly define equilibrium employment and labor market tightness in any static environment as functions $N(c)$ and $\theta(c)$ of recruiting cost c. Proposition 2 shows that despite diminishing returns, jobs are not rationed in the SZ model as the economy converges to full employment when matching frictions disappear.

PROPOSITION 2 (Full employment in SZ model)**.** *Under Assumptions 3 and 4, for any technology $a \in (0,+\infty)$, $\lim_{c\to 0}\theta(c) = +\infty$ and $\lim_{c\to 0} N(c) = 1$.*

A diagram in Figure 1 represents equilibrium condition (9). The downward-sloping line is the marginal profit from hiring labor gross of recruiting expenses, on the left-hand side of (9). Here,

[10] When $\alpha = 1$, equilibrium condition (9) is the same as equilibrium condition (8) in the MP model. This is because the Nash bargaining solution and the Stole and Zwiebel (1996) bargaining solution are identical when the production function exhibits constant marginal returns to labor.

the gross marginal profit is the marginal product of labor, minus the component of the wage independent of labor market tightness θ and recruiting cost c, minus the marginal change in the wage bill implied by the renegotiation of the wage between the firm and all the workers. The upward-sloping line is marginal recruiting expenses, on the right-hand side of (9). The sole difference from the MP model is that the gross marginal profit is downward sloping, because of diminishing marginal returns to labor. Jobs, however, are not rationed either in the SZ model: when recruiting cost c decreases to 0, the marginal-recruiting-expense curve shifts down; the gross-marginal-profit curve is independent of c and positive despite sloping down—it intercepts the $N = 1$ line at $\alpha \cdot (1-\beta)/[1-\beta \cdot (1-\alpha)] > 0$; therefore, the economy converges to full employment when c decreases to 0.

From the perspective of bilateral bargaining, the surplus from a marginal match always remains positive even though it decreases with aggregate employment because of diminishing marginal returns. When a marginal worker is recruited, intra-firm bargaining allocates a positive share of the marginal surplus to the firm, and reduces the wage paid to all workers in the firm. Accordingly, once recruiting expenses are sunk, the marginal profit from any new match created is positive. When the recruiting cost is zero, any match generates a positive net profit, and employers expand employment until all the labor force is employed. In spite of diminishing marginal returns to labor, jobs are not rationed because wages fall sufficiently when an increase in employment reduces the marginal product of labor.

3.3 Mortensen-Pissarides model with Rigid real wages (MPR Model)

I assume constant marginal returns to labor (Assumption 1) and introduce the Blanchard and Galí (2010) wage schedule, which only partially adjusts to technology shocks.

ASSUMPTION 5 (Wage rigidity)**.** There exists $\gamma \in [0,1)$ and $w_0 \in (0,+\infty)$ such that

$$W(N_t(i), \theta_t, N_t, a_t) = w_0 \cdot a_t^{\gamma}.$$

The MPR model, characterized by Assumptions 1 and 5, retains the key elements of the search-and-matching models with rigid real wages studied in Shimer (2004), Hall (2005a), and Blanchard and Galí (2010). The main departure from the MP model is the introduction of wage rigidity. Nonetheless, if technology is bounded: $a \in [\underline{a}, \overline{a}]$, the rigid wage schedule satisfies the equilibrium requirement that no inefficient separations occur if $w_0 \leq \underline{a}^{1-\gamma}$ (Hall 2005a). Since wages are rigid ($\gamma < 1$), they are not proportional to technology and the invariance property of the MP and SZ models does not hold: labor market tightness fluctuates in this model.

In a static environment, the Euler equation (7) becomes[11]

$$1 - w_0 \cdot a^{\gamma - 1} = c \cdot \frac{1 - \delta \cdot (1 - s)}{q(\theta)}. \tag{10}$$

Equations (3) and (10) implicitly define equilibrium employment and labor market tightness as functions $N(a,c)$ and $\theta(a,c)$ of technology a and recruiting cost c. Proposition 3 shows that in spite of wage rigidity, jobs are not rationed in the MPR model.

PROPOSITION 3 (Full employment in MPR model)**.** *Under Assumptions 1 and 5, for any a such that* $a \geq w_0^{1/(1-\gamma)}$, $\lim_{c \to 0} \theta(a,c) = +\infty$ *and* $\lim_{c \to 0} N(a,c) = 1$. *If* $a \leq w_0^{1/(1-\gamma)}$*, for any* $c > 0$, $\theta(a,c) = 0$ *and* $N(a,c) = 0$.

A diagram in Figure 1 represents equilibrium condition (10). The horizontal line is marginal profit gross of recruiting expenses, which is marginal product of labor minus wage, on the left-hand side of (10). The upward-sloping line is marginal recruiting expenses, on the right-hand side of (10). The difference with the MP model is that gross marginal profit fluctuates when technology changes, because of wage rigidity. Jobs, however, are not rationed in the MPR model either: when recruiting cost c decreases to 0, the marginal-recruiting-expense curve shifts down; the gross-marginal-profit curve is independent of c and positive for any technology level $a \geq w_0^{1/(1-\gamma)}$; therefore, the economy converges to full employment when c decreases to 0.

[11] Let θ^* solve (8). If technology follows a martingale, equilibrium condition (8) in the MP model makes the same prediction as equilibrium condition (10) for $\gamma = 1$ and

$$w_0 = \frac{c \cdot \beta}{1 - \beta} \cdot \left\{ \frac{1}{q(\theta^*)} + \delta \cdot (1 - s) \cdot \left(\theta^* - \frac{1}{q(\theta^*)} \right) \right\}.$$

A constant wage is not the outcome of any bargaining, so it could allocate a negative share of the bilateral surplus from a match to the firm or the worker. Since I assume constant marginal returns to labor, the surplus of any match is proportional to the difference between the level of technology and the flow value of being unemployed, and it is independent of aggregate employment. For the equilibrium condition of private efficiency to be respected, the wage must be below the level of technology; otherwise any match that generates a positive surplus would be dissolved inefficiently. As a consequence, any match generates the same positive profit once recruiting expenses are sunk. Without recruiting expenses, the net profit from any match is positive and jobs are created until all the labor force is employed. If the wage is low enough for one match to be profitable, infinitely many jobs would be profitable without recruiting expenses and the economy would operate at full employment in spite of wage rigidity.

4 Cyclicality of Frictional and Rationing Unemployment

In existing models, there would not be any unemployment without matching frictions. By construction, matching frictions are the sole source of unemployment. This section presents a model in which unemployment may result from both matching frictions and job rationing. I present one possible source of rationing: the combination of some real wage rigidity with diminishing marginal returns to labor. I study theoretically how the interaction of these two sources generates cyclical fluctuations in unemployment.

4.1 Two assumptions

I assume diminishing marginal returns to labor in production (Assumption 3) and real wage rigidity (Assumption 5).[12] The introduction of wage rigidity into the model follows the reduced-form approach of the literature.[13] The simple wage schedule in Assumption 5 could be interpreted as

[12] As shown in Section 3, the assumptions have been introduced separately in existing models, but have never been combined.

[13] Most macroeconomic models in the search literature use reduced-form approaches to wage rigidity: Shimer (2004), Hall (2005a), and Blanchard and Galí (2010) assume simple rigid-wage schedules; Gertler and Trigari (2009)

the outcome of complex wage-setting processes normally occurring in firms. Historic and ethnographic evidence presented below suggests that the schedule captures critical elements of the behavior of wages. As in Hall (2005a), it is possible to sustain an equilibrium in which wages never result in an allocation of labor that is inefficient from the joint perspective of the worker-firm pair, even though wages are not completely flexible. For instance, Lemma 3 states that under Assumption 6, inefficient worker-firm separations can be avoided with high probability if wages are flexible enough.

ASSUMPTION 6. $\log(a_{t+1}) = \log(a_t) + z_t$ with $z_t \sim N(0, \sigma^2)$ and $\sigma \in (0, +\infty)$.

LEMMA 3. *Under Assumptions 3, 5, and 6, a sufficient condition on γ such that inefficient separations occur with a probability below p is*

$$\gamma \geq 1 - (1-\alpha) \cdot \frac{\log(1-s)}{\sigma \cdot \Phi^{-1}(p)},$$

where Φ is the cumulative distribution function of $N(0,1)$. Under this condition, there are no inefficient separations when the technology shock z_t satisfies $\Phi(z_t) \geq p$.

Under a technical assumption on the stochastic process followed by technology, Lemma 3 shows that some rigidity can be accommodated in equilibrium in a stochastic environment, as inefficient separations are guaranteed to be avoided as long as the amplitude of negative technology shocks is not too large.[14] Importantly, this condition is independent from recruiting costs. It is therefore also valid in an environment without matching frictions. The condition is less stringent when the separation rate s is higher because exogenous separations reduce employment in firms at the beginning of each period, which increases the marginal product of labor through diminishing returns. For a given wage, a higher marginal product makes inefficient separations less likely. Through the same mechanism, both lower production-function parameter α and lower standard deviation of technology shocks σ reduce the lower bound on the elasticity γ described in Lemma 3.

assume that wages can only be renegotiated at distant time intervals.

[14]I chose Assumption 6 for its simplicity and its empirical relevance. Similar results can be derived with more complex assumptions on the stochastic process followed by technology.

4.2 Existence of job rationing

I concentrate on a static environment.[15] Equation (7) simplifies to

$$\alpha \cdot N^{\alpha-1} - w_0 \cdot a^{\gamma-1} = [1-(1-s)\cdot\delta]\cdot\frac{c}{q(\theta)}. \tag{11}$$

Equations (3) and (11) uniquely define equilibrium employment and labor market tightness as implicit functions $N(a,c)$ and $\theta(a,c)$ of technology and recruiting cost.

PROPOSITION 4 (Existence of job rationing)**.** *Under Assumptions 3 and 5, for any technology* $a \in (0, a^R)$ *with*

$$a^R = \left(\frac{w_0}{\alpha}\right)^{\frac{1}{1-\gamma}},$$

there exists a unique $N^R(a) \in (0,1)$ *such that* $\lim_{c\to 0} N(a,c) = N^R(a)$. $N^R(a)$ *solves*

$$\alpha \cdot N^{\alpha-1} - w_0 \cdot a^{\gamma-1} = 0, \tag{12}$$

and is therefore given by

$$N^R(a) = \left(\frac{\alpha}{w_0}\right)^{\frac{1}{1-\alpha}} \cdot a^{\frac{1-\gamma}{1-\alpha}}. \tag{13}$$

With technology $a \in (0, a^R)$, equation (12) admits a unique solution $N^R(a) < 1$. $N^R(a)$ is equilibrium employment in an environment without matching frictions for, in the absence of frictions, $c = 0$ and equilibrium condition (11) becomes equation (12). Proposition 4 states that jobs are rationed when technology is low enough, because the economy remains below full employment even when matching frictions disappear. The mechanism leading to job rationing is simple. The wage agreed upon by firms and job applicants does not fall as much as the marginal product of labor when technology declines, because of wage rigidity. Thus, the wage may be above the marginal product of the last workers in the labor force, because of diminishing marginal returns to labor. In that case, irrespective of matching frictions, not all workers can be profitably hired.

[15] In the Appendix, I compare the unemployment and labor market tightness series obtained when I solve this model exactly, and when I solve it in a series of static environment. While the time series obtained with these two numerical solution methods are quantitatively different, they are qualitatively very similar.

Even without matching frictions, the labor market may not clear because there is no mechanism to bring wages down to the market-clearing level. Firms meet job applicants sequentially, one at a time. The timing of meetings prevents firms from auctioning off jobs as in a perfectly competitive setting. Yet, the wage is privately efficient because it is below the marginal productivity of any worker paired with a firm, so the firm makes a non-negative profit by paying the wage and pursuing the match.

To measure the shortage of jobs on the labor market, independent of matching frictions, I define rationing unemployment U^R as

$$U^R(a) \equiv 1 - N^R(a) = 1 - \left(\frac{\alpha}{w_0}\right)^{\frac{1}{1-\alpha}} \cdot a^{\frac{1-\gamma}{1-\alpha}}. \tag{14}$$

Matching frictions impose positive recruiting expenses on firms, which contribute to the marginal cost of labor, and lead firms to curtail employment. To measure unemployment attributable to positive recruiting costs, I define frictional unemployment U^F as

$$U^F(a,c) \equiv U(a,c) - U^R(a). \tag{15}$$

A diagram in Figure 1 represents equilibrium condition (11). The downward-sloping line is gross marginal profit, on the left-hand side of (11). Here, gross marginal profit is marginal product of labor minus the wage. The upward-sloping line is marginal recruiting expenses, on the right-hand side of (11). Rationing unemployment is unemployment prevailing when the recruiting cost c converges to zero. It is obtained at the intersection of the gross-marginal-profit curve with the x-axis because the marginal-recruiting-expense curve shifts down to the x-axis when c falls to 0. Total unemployment is obtained at the intersection of the gross-marginal-profit and marginal-recruiting-expense curves, and frictional unemployment is the difference between total and rationing unemployment. The diminishing-return and wage-rigidity assumptions (Assumptions 3 and 5) are necessary for the existence of job rationing. Without the diminishing-return assumption , the gross-marginal-profit curve would be flat and would never intersect the x-axis on $(0,1)$, so rationing unemployment would always be nil. Without the wage-rigidity assumption, the gross-marginal-profit curve would not shift. There would be no guarantee that it intersects the x-axis and rationing unemployment may never be positive. With rigid wages, the intersection occurs for low levels of technology.

This result can be interpreted from the perspective of bilateral bargaining. In the model with job rationing, there is a range of technology and employment in which the wage would be too high for firms to extract a positive share of the surplus from worker-firm matches. In fact, when technology is low enough and employment is high enough, the wage is above the marginal product of labor, and, even when recruiting expenses are sunk, firms would make a negative profit from a match. Unlike in the models of Section 3, jobs are rationed when technology is low enough: even if recruiting cost was zero, workers could not all be profitably employed and some unemployment would remain.

4.3 Comparative statics

To understand how job rationing and matching frictions generate cyclical fluctuations in unemployment, I study how technology, as well as total, rationing and frictional unemployments comove by performing comparative statics with respect to technology.

PROPOSITION 5 (Cyclicality of frictional and rationing unemployment)**.** *Under Assumptions 3 and 5, for any technology $a \in (0, a^R)$: $\partial U/\partial a < 0$, $\partial U^R/\partial a < 0$, and $\partial U^F/\partial a > 0$.*

Around any equilibrium at which jobs are rationed, we have the following comparative-static results: when technology decreases, total unemployment increases, rationing unemployment increases, but paradoxically, frictional unemployment decreases. This proposition uncovers a novel mechanism behind unemployment fluctuations. In expansions, when technology is high enough, matching frictions account for all unemployment. But when technology is low enough and falls further in recessions, the rationing of jobs becomes more acute, driving the rise in total unemployment. Simultaneously, the number of unemployed workers attributable to matching frictions falls.

A diagram in Figure 1 provides intuition. When technology decreases, the gross-marginal-profit curve shifts down because the marginal product of labor falls while rigid wages adjust downwards only partially. At the current employment level, gross marginal profit falls short of marginal recruiting expenses. Firms reduce hiring to increase gross marginal profit. Lower recruiting efforts by firms reduce labor market tightness and recruiting expenses. The adjustment process continues until a new equilibrium with higher unemployment is reached, when gross marginal profit equals marginal recruiting expenses.

When technology decreases, the gross-marginal-profit curve shifts down and rationing unemployment is mechanically higher. Irrespective of matching frictions, the shortage of jobs is more acute, and there are more unemployed workers and fewer vacancies. Once frictions are taken into account, a firm posting a vacancy will receive many applications from the large pool of unemployed workers, and it will be able to fill its vacancy rapidly at low cost. From the employment level prevailing when $c = 0$, a smaller reduction in employment suffices to bring the economy to equilibrium. Consequently, frictional unemployment diminishes.

4.4 Empirical evidence

There is ample evidence in favor of the two critical assumptions of diminishing returns and wage rigidity. The model aims to describe cyclical fluctuations, and production inputs do not adjust fully to changes in employment at business cycle frequency. Capital is especially slow to adjust. If capital and labor are the only production inputs and capital is assumed to be constant in the short run, the production function takes the form proposed in Assumption 3 and exhibits diminishing marginal returns to labor. At longer horizon, the production function could exhibit diminishing marginal returns to labor if some production inputs such as land or managerial talent are in fixed supply.

Furthermore, ethnographic evidence supports the rigid wage schedule chosen in Assumption 5. The schedule depends neither on the marginal product of labor nor on labor market conditions. The disconnect between wages and both marginal productivity and labor market conditions can be explained by the rise of the personnel management movement after World War I, which led to the widespread adoption of internal labor markets within firms (Jacoby 1984). Doeringer and Piore

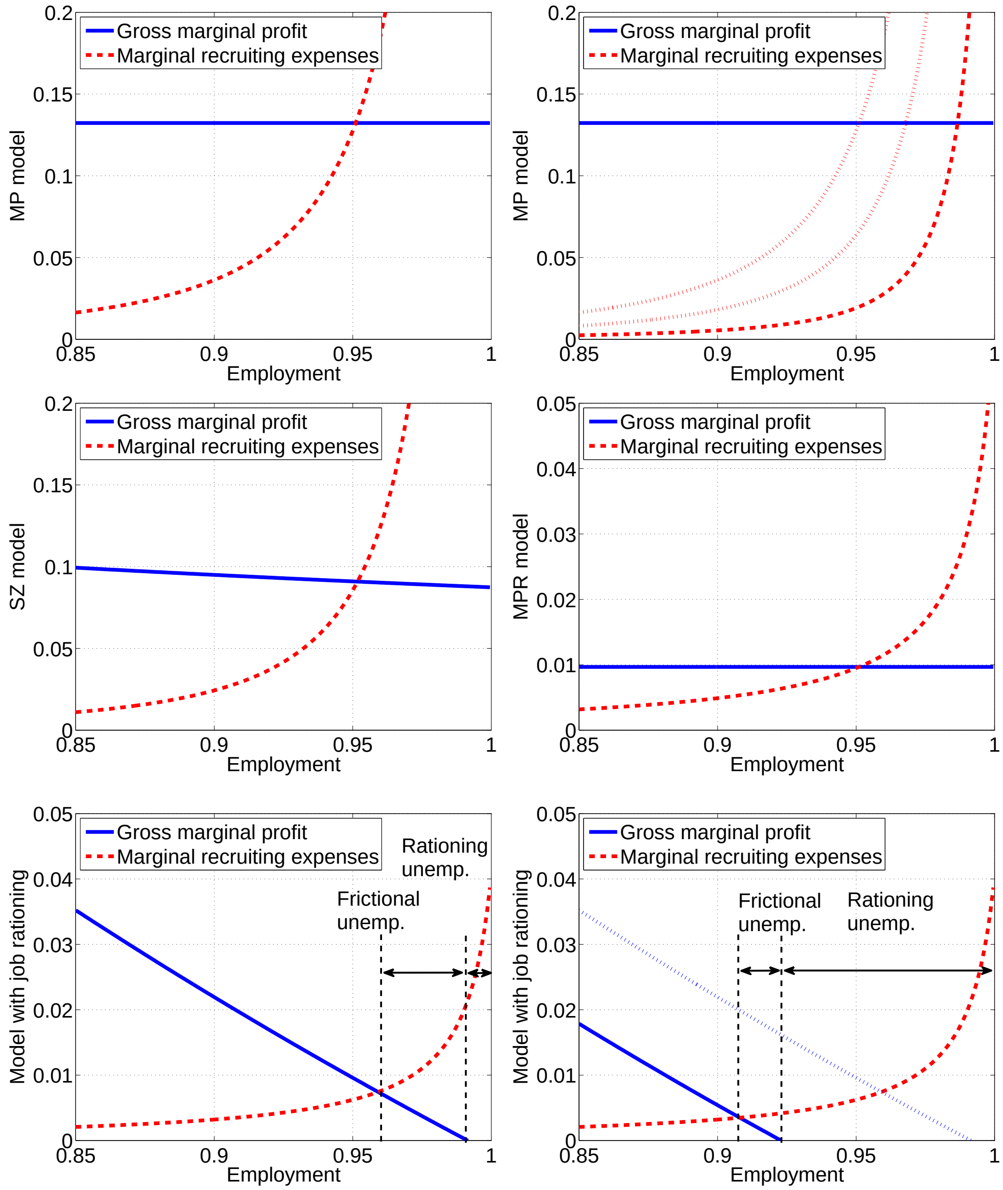

Figure 1: Equilibria in various search-and-matching models

Notes: These diagrams describe equilibria in static environments in the MP, SZ, and MPR models, as well as in the model with job rationing. The two diagrams for the MP model represent the equilibrium for a calibrated recruiting cost (left) and lower recruiting costs (right). The two diagrams for the model with job rationing represent the decomposition of unemployment into rationing and frictional unemployment for high technology (left) and lower technology (right). Diagrams are obtained by plotting equilibrium conditions (8) (for the MP model), (9) (for the SZ model), (10) (for the MPR model), and (11) (for the model with job rationing) for a continuum of employment levels. The model with job rationing is calibrated in Table 1. Other models are calibrated in the Appendix.

(1971) document that in internal labor markets, motivated by concerns for equity within firms, wages are tied to job description and are insensitive to labor market and marginal productivity conditions. Furthermore, labor market institutions sometimes hamper downward wage adjustments in the face of slack labor markets. For instance, Temin (1990) and Cole and Ohanian (2004) explain the persistence of high real wages during the Great Depression by the National Industry Recovery Act of 1933. More recently, unions vetoed nominal pay cuts during the Finnish depression of 1991-1993 despite rampant unemployment (Gorodnichenko et al. 2009). Lastly, managerial best practices across countries and industries oppose pay cuts even when the labor market is slack, because managers believe pay cuts antagonize workers and reduce profitability (Agell and Lundborg 1995; Bewley 1999; Blinder and Choi 1990; Campbell and Kamlani 1997). Natural experiments studying workers' reactions to pay cuts strongly support managers' views (Krueger and Mas 2004; Mas 2006).

5 Quantitative Analysis

The previous section presented evidence supporting the diminishing-return and wage-rigidity assumptions. In this section, I directly calibrate wage rigidity and diminishing marginal returns to be consistent with microdata on wage dynamics and aggregate data on the labor share. I move beyond the comparative-static results by computing impulse response function in the fully dynamic model. I use the Fair and Taylor (1983) algorithm to quantify comovements in technology, total unemployment, frictional unemployment, and rationing unemployment when the model is simulated with actual U.S. technology. A byproduct of the quantitative analysis is to verify that the calibrated model describes well the U.S. labor market.

5.1 Calibration

I calibrate all parameters at weekly frequency (a week is 1/4 of a month and 1/12 of a quarter). Table 1 summarizes calibrated parameters. I first estimate the stochastic process for technology in U.S. data. I construct log technology as a residual $\log(a) = \log(Y) - \alpha \cdot \log(N)$. Output Y

and employment N are seasonally-adjusted quarterly real output and employment in the nonfarm business sector constructed by the Bureau of Labor Statistics (BLS) Major Sector Productivity and Costs (MSPC) program. The sample period is 1964:Q1–2009:Q2. To isolate fluctuations at business cycle frequency , I follow Shimer (2005) and take the difference between log technology and a low frequency trend—a Hodrick-Prescott (HP) filter with smoothing parameter 10^5. I estimate detrended log technology as an AR(1) process: $\log(a_{t+1}) = \rho \cdot \log(a_t) + z_{t+1}$ with $z_{t+1} \sim N(0, \sigma^2)$. With quarterly data, I obtain an autocorrelation of 0.897 and a conditional standard deviation of 0.0087, which yields $\rho = 0.991$ and $\sigma = 0.0026$ at weekly frequency.

I now calibrate the labor market parameters: job destruction rate (s), recruiting cost (c), and matching function (ω, η). I estimate the job destruction rate from the seasonally-adjusted monthly series for total separations in all nonfarm industries constructed by the BLS from the Job Openings and Labor Turnover Survey (JOLTS) for the December 2000–June 2009 period.[16] The average separation rate is 0.038, so $s = 0.0095$ at weekly frequency. I estimate the recruiting cost from microdata gathered by Barron et al. (1997) and find that on average, the flow cost of opening a vacancy amounts to 0.098 of a worker's wage.[17] This number accounts only for the labor cost of recruiting. Silva and Toledo (2005) account for other recruiting expenses such as advertising costs, agency fees, and travel costs, to find that 0.42 of a worker's monthly wage is spent on each hire. Unfortunately, they do not report recruiting times. Using the average monthly job-filling rate of 1.3 in JOLTS, 2000–2009, the flow cost of recruiting could be as high as 0.54 of a worker's wage. I calibrate recruiting cost as 0.32 of a worker's wage, the midpoint between the two previous

[16]December 2000–June 2009 is the longest period for which JOLTS is available. Comparable data are not available before this date.

[17]Using the 1980 Employment Opportunity Pilot Project survey (2,994 observations), they find that on average employers spend 5.7 hours per offer, make 1.02 offers per hired worker, and take 13.4 days to fill a position. Hence the flow cost of maintaining a vacancy open is $5.7/8 \times 1.02/13.4 \approx 0.054$ of a worker's wage. Adjusting for the possibility that hiring is done by supervisors who receive above-average wages as in Silva and Toledo (2005), the flow cost of keeping an open vacancy is 0.071 of a worker's wage. With the 1982 Employment Opportunity survey (1,270 observations), the corresponding numbers are 10.4 hours, 1.08 offers, 17.2 days, and the flow cost is 0.106. With the 1993 survey conducted by the authors for the W. E. Upjohn Foundation for Employment Research (210 observations), the numbers are 18.8 hours, 1.16 offers, 30.3 days, and the flow cost is 0.117.

estimates.[18] Next, I specify the matching function as

$$h(U,V) = \omega \cdot U^{\eta} \cdot V^{1-\eta}$$

with $\eta = 0.5$, in line with empirical evidence (Petrongolo and Pissarides 2001). Last, I estimate matching efficiency ω with seasonally-adjusted monthly series for number of hires, vacancy level, and unemployment level constructed by the BLS from JOLTS and the Current Population Survey (CPS) over the 2000–2009 period. For each month i, I calculate θ_i as the ratio of vacancies to unemployment and the job-finding probability f_i as the ratio of hires to unemployment. The least squares estimate of ω, which minimizes $\sum_i (f_i - \omega \cdot \theta_i^{1-\eta})^2$, is 0.93. At weekly frequency, $\omega = 0.23$.

Next I calibrate the elasticity γ of wages with respect to technology based on estimates obtained from panel data recording wages of individual workers. These microdata are more adequate because they are less prone to composition effects than aggregate data. The survey of the literature by Pissarides (2009) places the productivity-elasticity of wages of existing jobs in the 0.2–0.5 range in U.S. data. Pissarides (2009) argues, however, that models should be calibrated with the elasticity of wages of newly created jobs and not existing jobs. Estimating wage rigidity for newly created jobs is a arduous task. The standard approach is to measure wage rigidity among job movers. Unfortunately the composition of jobs accepted over the cycle fluctuates, biasing the analysis. Workers accept lower-paid, stop-gap jobs in recessions, and move to better jobs during expansions, biasing the estimated elasticity upwards. This composition effect is difficult to control for. A recent study by Haefke et al. (2008) estimates the elasticity of wages of job movers with respect to productivity using panel data for U.S. workers. They do not control for the cyclical composition of jobs; thus, their estimate is an upper bound on the elasticity of wages. For a sample of production and supervisory workers over the period 1984–2006, they obtain a productivity-elasticity of total earnings of 0.7. I set $\gamma = 0.7$, a conservative estimate of wage rigidity.[19]

[18] Using the average unemployment rate and labor market tightness in JOLTS, I find that 0.89 percent of the total wage bill is spent on recruiting.

[19] This estimate of wage rigidity is conservative for two reasons: (i) 0.7 is an upward-biased estimate of the elasticity of wages; (2) 0.7 is an estimate of the elasticity of wages with respect to labor productivity Y/N, whereas γ is the elasticity of wages with respect to technology $a = Y/N^{\alpha}$. While technology and productivity are highly correlated, productivity is less volatile than technology and therefore an estimate of the elasticity of wages with respect to

Table 1: PARAMETER VALUES IN SIMULATIONS OF THE MODEL WITH JOB RATIONING

	Interpretation	Value	Source
δ	Discount factor	0.999	Corresponds to 5% annually
$\overline{a}$	Steady-state technology	1	Normalization
ρ	Autocorrelation of technology	0.991	MSPC, 1964–2009
σ	Standard deviation of shocks	0.0026	MSPC, 1964–2009
s	Separation rate	0.0095	JOLTS, 2000–2009
ω	Efficiency of matching	0.23	JOLTS, 2000–2009
η	Unemployment-elasticity of matching	0.5	Petrongolo and Pissarides (2001)
γ	Wage rigidity	0.70	Haefke et al. (2008)
c	Recruiting cost	0.21	0.32× steady-state wage
α	Returns to labor	0.67	Matches labor share= 0.66
w_0	Steady-state real wage	0.67	Matches unemployment = 5.8%

Note: All parameters are calibrated at weekly frequency.

So far, I have estimated parameters from microdata or aggregate data, independently of the model. To conclude, I calibrate the steady-state wage w_0 and the production function parameter α such that the steady state of the model matches average unemployment $\overline{u} = 5.8\%$ and average labor share $\overline{ls} = 0.66$ in U.S. data. Average unemployment is computed from the seasonally-adjusted monthly unemployment rate constructed by the BLS from the CPS for the 1964–2009 period. These targets imply steady-state employment $\overline{n} = 0.951$ and steady-state labor market tightness $\overline{\theta} = 0.45$. In steady state $\overline{a} = 1$ and $\overline{ls} \equiv (\overline{w} \cdot \overline{n}) / \overline{y} = w_0 \cdot \overline{n}^{1-\alpha}$. Therefore (11) becomes

$$\overline{ls} = \alpha - [1 - \delta(1-s)] \cdot \frac{c}{q(\overline{\theta})} \cdot \overline{n}^{1-\alpha},$$

which yields $\alpha = 0.67$ and $w_0 = \overline{ls} \cdot \overline{n}^{\alpha-1} = 0.67$.

technology would be below 0.7.

Table 2: SUMMARY STATISTICS, QUARTERLY U.S. DATA, 1964–2009.

	U	V	θ	W	Y	a
Standard Deviation	0.168	0.185	0.344	0.021	0.029	0.019
Autocorrelation	0.914	0.932	0.923	0.950	0.892	0.871
Correlation	1	-0.886	-0.968	-0.239	-0.826	-0.478
	–	1	0.974	0.191	0.785	0.453
	–	–	1	0.220	0.828	0.479
	–	–	–	1	0.512	0.646
	–	–	–	–	1	0.831
	–	–	–	–	–	1

Notes: All data are seasonally adjusted. The sample period is 1964:Q1–2009:Q2. Unemployment rate U is quarterly average of monthly series constructed by the BLS from the CPS. Vacancy rate V is quarterly average of monthly series constructed by merging data constructed by the BLS from the JOLTS and data from the Conference Board, as detailed in the text. Labor market tightness θ is the ratio of vacancy to unemployment. Real wage W is quarterly, average hourly earning in the nonfarm business sector, constructed by the BLS CES program, and deflated by the quarterly average of monthly CPI for all urban households, constructed by BLS. Y is quarterly real output in the nonfarm business sector constructed by the BLS MSPC program. $\log(a)$ is computed as the residual $\log(Y) - \alpha \cdot \log(N)$ where N is quarterly employment in the nonfarm business sector constructed by the BLS MSPC program. All variables are reported in log as deviations from an HP trend with smoothing parameter 10^5.

5.2 Simulated moments

I verify that the model provides a sensible description of reality by comparing important simulated moments to their empirical counterparts. I focus on second moments of the unemployment rate U, the vacancy rate V, labor market tightness $\theta = V/U$, real wage W, output Y, and technology a. Table 2 presents empirical moments in U.S. data for the 1964:Q1–2009:Q2 period. Unemployment rate, output, and technology are described above. The real wage is quarterly, average hourly earning in the nonfarm business sector constructed by the BLS Current Employment Statistics (CES) program, and deflated by the quarterly average of monthly Consumer Price Index (CPI) for all urban households, constructed by BLS. To construct a vacancy series for the 1964–2009 period, I merge the vacancy data from JOLTS for 2001–2009, with the Conference Board help-wanted advertising index for 1964–2001.[20] I take the quarterly average of the monthly vacancy-level series,

[20]The Conference Board index measures the number of help-wanted advertisements in major newspapers. It is a standard proxy for vacancies (for example, Shimer 2005). The merger of both datasets is necessary because JOLTS

and divide it by employment to obtain a vacancy-rate series. I construct labor market tightness as the ratio of vacancy to unemployment. All variables are seasonally-adjusted, expressed in logs, and detrended with a HP filter of smoothing parameter 10^5.

Next, I log-linearize my model around steady state and perturb it with i.i.d. technology shocks $z_t \sim N(0, 0.0026)$.[21] I obtain weekly series of log-deviations for all the variables. I record values every 12 weeks for quarterly series (Y, W, a). I record values every 4 weeks and take quarterly averages for monthly series (U, V, θ). I discard the first 100 weeks of simulation to remove the effect of initial conditions. I keep 100 samples of 182 quarters (2,184 weeks), corresponding to quarterly data from 1964:Q1 to 2009:Q2. Each sample provides estimates of the means of model-generated data. I compute standard deviations of estimated means across samples to assess the precision of model predictions. Table 3 presents the resulting simulated moments. Simulated and empirical moments for technology are similar because I calibrate the technology process to match the data. All other simulated moments are outcomes of the mechanics of the model.

The fit of the model is very good along several critical dimensions. First, the model amplifies technology shocks as much as observed in the data. In U.S. data, a 1-percent decrease in technology increases unemployment by 4.2 percent and reduces vacancy by 4.3 percent. It therefore reduces labor market tightness, measured by the vacancy-unemployment ratio, by 8.6 percent.[22] In the model, a 1-percent decrease in technology increases unemployment by 6.2 percent, reduces vacancy by 7.0 percent, and therefore reduces labor market tightness by 13.2 percent. Second, the response of wages to technology shocks in the model and the data are indistinguishable. In both cases, a 1-percent decrease in technology decreases wages by 0.7 percent. Third, simulated and empirical slopes of the Beveridge curve are almost identical. The slope, measured by the correlation of unemployment with vacancy, is -0.92 in the model and -0.89 in the data. Last, autocorrelations of all variables and behavior of output in the model match the data.

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began only in December 2000 while the Conference Board data become less relevant after 2000, owing to the major role played by the Internet as a source of job advertising.

[21]The Appendix describes the log-linear model in details.

[22]The elasticity of unemployment with respect to technology ε_a^U is the coefficient obtained in an OLS regression of log unemployment on log technology. This coefficient can be derived from Table 2: $\varepsilon_a^U = \rho(U,a) \times \sigma(U)/\sigma(a) = -0.478 \times 0.168/0.019 = -4.2$. All other elasticities are computed similarly. Since $\theta = V/U$, $\varepsilon_a^\theta = \varepsilon_a^V - \varepsilon_a^U$.

Table 3: SIMULATED MOMENTS WITH TECHNOLOGY SHOCKS

	U	V	θ	W	Y	a
Standard Deviation	0.119	0.142	0.256	0.014	0.024	0.019
	(0.021)	(0.022)	(0.044)	(0.002)	(0.004)	(0.003)
Autocorrelation	0.939	0.847	0.913	0.884	0.898	0.884
	(0.020)	(0.045)	(0.028)	(0.036)	(0.032)	(0.036)
	1	-0.931	-0.979	-0.986	-0.991	-0.986
		(0.020)	(0.007)	(0.004)	(0.003)	(0.004)
	–	1	0.986	0.935	0.929	0.935
			(0.004)	(0.019)	(0.021)	(0.019)
	–	–	1	0.975	0.974	0.975
				(0.008)	(0.008)	(0.008)
Correlation	–	–	–	1	0.999	1.000
					(0.001)	(0.000)
	–	–	–	–	1	0.999
						(0.000)
	–	–	–	–	–	1

Notes: Results from simulating the log-linearized model with stochastic technology. All variables are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 100 simulations) are reported in parentheses.

However, the model does not perform well along one important dimension: the correlation of labor market variables and wages with technology. Simulated correlations of unemployment, vacancy, and labor market tightness with technology are close to 1, but empirical correlations are below 0.5. Similarly, aggregate wages vary twice as much in the data as in the model. Demand shocks, financial disturbances, and nominal rigidities, absent from the model but empirically important, could explain these discrepancies. The simplicity of the model prevents it from achieving the degree of volatility observed in the data: while amplification of technology shocks is as strong as in the data, simulated standard deviations of wage W and labor market variables U, V, and θ are inferior to their empirical counterparts because some sources of volatility are omitted.

This simulation exercise contributes to a large literature on the role of wage rigidity in explaining unemployment fluctuations. Following the Shimer (2005) critique of the standard search-and-matching model, several papers introduced wage rigidity to increase unemployment volatility (Gertler and Trigari 2009; Hall 2005a; Hall and Milgrom 2008). These papers were criticized for exaggerating the rigidity of wages in spite of empirical evidence suggesting that wages for newly hired workers are quite flexible (Haefke et al. 2008; Mortensen and Nagypál 2007; Pissarides 2009). Calibrating wage rigidity with an estimate from microdata on new hires, I show that in fact even a small amount of wage rigidity sufficiently amplifies technology shocks.[23]

5.3 Impulse response functions

To confirm the comovements of technology with unemployment and its components in a fully dynamic model, I compute impulse response functions (IRFs) in the log-linear model.[24] In steady state, $\overline{u} = 5.8\%$, $\overline{u}^R = 1 - (\alpha/w_0)^{1/(1-\alpha)} = 2.4\%$, and $\overline{u}^F = 3.4\%$. Steady-state rationing unemployment is positive because steady-state technology $\overline{a} = 1$ is below $a^R = 1.025$, which is is the lowest technology level for which all unemployment is frictional. By contrast, in a static environment with $a = a^R$, $U = U^F = 4.8\%$ and $U^R = 0\%$. Steady-state rationing unemployment depends naturally on the steady-state wage w_0 and diminishing returns α, but not on wage rigidity γ.

Next, I extend the definitions of rationing and frictional unemployment given by (14)– (15) to a

[23] My model matches empirical evidence better than the models presented in Section 3, because both wage rigidity and diminishing returns contribute to improving empirical fit. On the one hand, Shimer (2005) showed that a search-and-matching model in which wages are Nash bargained is unable to amplify technology shocks. In this paper, I derive another version of this result: in the MP model with Nash bargaining and in the SZ model with Stole and Zwiebel (1996) bargaining, if recruiting cost and flow value of unemployment are linear in technology, and if technology is a martingale, labor market tightness is invariant to technology. This result, comparable to a result in Blanchard and Galí (2010), holds because the bargained wages are proportional to technology. Hence, neither the MP model nor the SZ model can fit the data. On the other hand, a simulation exercise shows that there is too much amplification in the MPR model. Following the same calibration strategy, I set $c = 0.32$ and $w_0 = 0.991$ for the MPR model. If wages are completely rigid ($\gamma = 0$), the simulated technology-elasticity of labor market tightness is more than 20 times the elasticity of 8.6 in U.S. data. If $\gamma = 0.7$, wages are as rigid as in my model but the technology-elasticity of labor market tightness remains more than 4 times as large as in the data. In the MPR model, technology shocks are overly amplified because of the absence of diminishing marginal returns to labor, which dampen the response to shocks.

[24] Applying Lemma 3 , I find that if $\gamma \geq 0.51$, wages are flexible enough to avoid inefficient separations with probability below 1 percent. With $\gamma \geq 0.62$, they occur with probability below 0.1 percent. Thus, with the calibration $\gamma = 0.7$, under a technology shock of one standard deviation, inefficient separations do not occur. I can safely linearize the system of equilibrium equations as described in Appendix.

stochastic environment. In period t, if $a_t \in (0, a^R)$, I define

$$U_t^R \equiv 1 - \left(\frac{\alpha}{w_0}\right)^{\frac{1}{1-\alpha}} \cdot a_t^{\frac{1-\gamma}{1-\alpha}} \tag{16}$$

$$U_t^F \equiv U_t - U_t^R. \tag{17}$$

If $a_t \notin (0, a^R)$, I define $U_t^R \equiv 0$ and $U_t^F \equiv U_t$. Let $\check{x}_t \equiv d\log(X_t)$ denotes the logarithmic deviation of variable X_t. Unemployment components are described by the following system of log-linear equations:

$$\check{u}_t^R = -\frac{1-\gamma}{1-\alpha} \cdot \frac{1-\overline{u}^R}{\overline{u}^R} \cdot \check{a}_t$$
$$\check{u}_t = \frac{\overline{u}-\overline{u}^R}{\overline{u}} \cdot \check{u}_t^F + \frac{\overline{u}^R}{\overline{u}} \cdot \check{u}_t^R.$$

Unlike the steady-state level $\overline{u}^R$ of rationing unemployment, its log-deviation $\check{u}_t^R$ does depend on wage rigidity γ: when wages are more rigid (γ is lower), rationing unemployment responds with more amplitude to a technology shock.

Figure 2 shows the IRFs to a negative technology shock of one standard deviation ($-\sigma = -0.0026$). On impact, output, consumption, labor market tightness, the number of hires, and wages fall discretely. The reduced number of hirings together with the constant amount of exogenous job destruction, lead unemployment to slowly build up and peak around 4 months after the technology shock, in line with the findings in Stock and Watson (1999). After a negative technology shock, rationing unemployment jumps on impact, whereas frictional unemployment drops. The IRFs uncover a dynamic effect that complements the comparative-static results of Section 4. When technology is in the interval $(0, a^R)$, and an adverse technology shock hits the economy, rationing unemployment increases immediately. This increase is the driving force behind the rise in total unemployment. As frictional unemployment falls on impact, matching frictions retard the increase of unemployment in the short run. They delay the spike of unemployment by about a quarter because of intertemporal substitution effects. In the periods following a drop in technology, firms intertemporally substitute recruiting from future periods to the present. They take

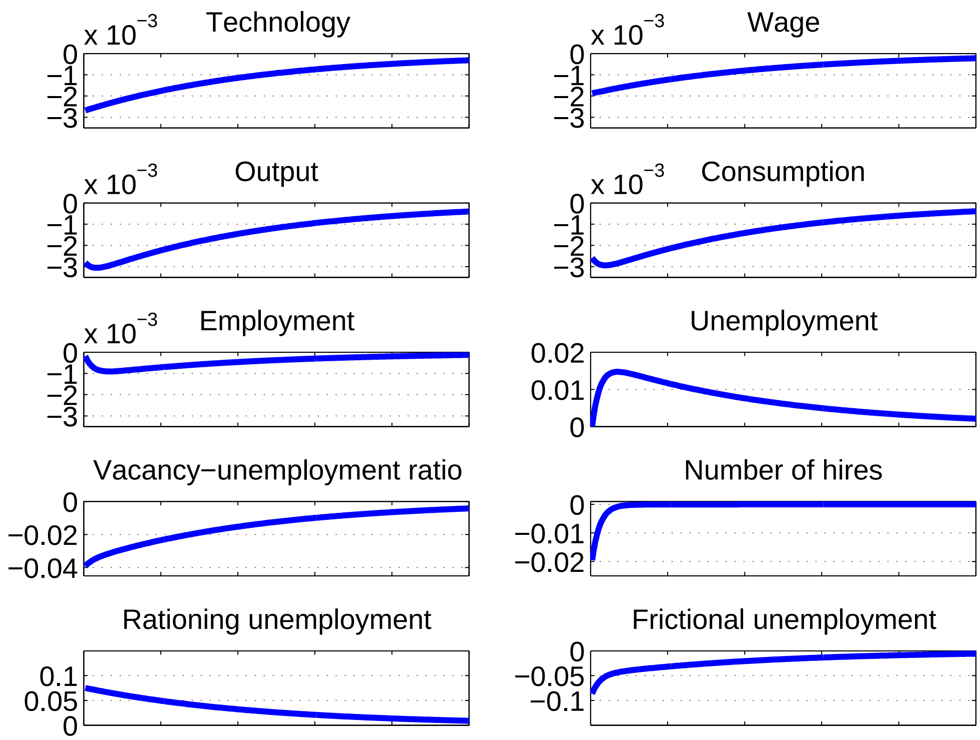

Figure 2: IRFs TO A NEGATIVE TECHNOLOGY SHOCK

Notes: Impulse response functions (IRFs) represent the logarithmic deviation from steady state for each variable. IRFs are obtained by imposing a negative technology shock of $-\sigma = -0.0026$ to the log-linear model. The time period displayed on the x-axis is 250 weeks.

advantage of a slack labor market to recruit at low cost now, instead of recruiting in a tighter labor market in the future. This dynamic effect, together with the comparative-static effect highlighted in Proposition 5, generate cyclical fluctuations in frictional unemployment.

5.4 Historical decomposition of unemployment

To better understand how unemployment and its components fluctuate over the cycle, I construct historical time series for rationing and frictional unemployment from the technology series measured in U.S. data. In this simulation, the economy departs substantially from the steady state so I do not use the log-linear model. Instead I solve exactly the nonlinear model with the Fair and Taylor (1983) shooting algorithm. This algorithm solves dynamic rational expectation models period by period. Each period, it iterates over the path of expected values for endogenous (employment and labor market tightness) and exogenous (technology) variables, until this path converges from an arbitrary path to a path of rational expectations, consistent with the predictions of the model.

To simplify computations, I approximate the AR(1) process for technology as a 200-state Markov chain (Tauchen 1986). Since the model operates at weekly frequency, I interpolate the quarterly technology series from the data into a weekly series. I discretize the weekly series in the state space of the Markov chain and simulate the model with the resulting series of states. Figure 3 shows that model-generated and actual unemployment match well.[25] Both series have the same standard deviation and their correlation is 0.55. The model explains a good amount of fluctuations in unemployment , even though the fit of the model is not perfect. For instance, actual unemployment reached 9.2 percent in 2009:Q2 whereas the model only predicts 8.1 percent, suggesting that factors other than a technological decline spurred unemployment in 2008–2009.

From technology measured in U.S. data and simulated unemployment, I generate rationing and frictional unemployment using (16) and (17). Figure 4 shows the resulting decomposition of simulated unemployment. When unemployment is below 5.0 percent, it is solely frictional. Above 5.0 percent, both rationing and frictional unemployment contribute to total unemployment. Rises in total unemployment are driven by increases in rationing unemployment; simultaneously, frictional unemployment falls. Indeed, spikes in unemployment are accompanied by sharp drops in frictional unemployment and steep rises in rationing unemployment, as illustrated by current events. The model predicts that in 2004:Q1, unemployment was at 4.8 percent, all of which was frictional. When unemployment peaked at 8.1 percent in 2009:Q2, frictional unemployment dropped to 1.8

[25]The simulated series displayed is obtained by extracting observations every 12 weeks from the weekly unemployment series generated by the model. The actual series displayed is obtained by taking the quarterly average of the monthly unemployment-rate series constructed by the BLS from the CPS, and detrending this quarterly series with an HP filter of smoothing parameter 10^5. These transformations make the two series comparable.

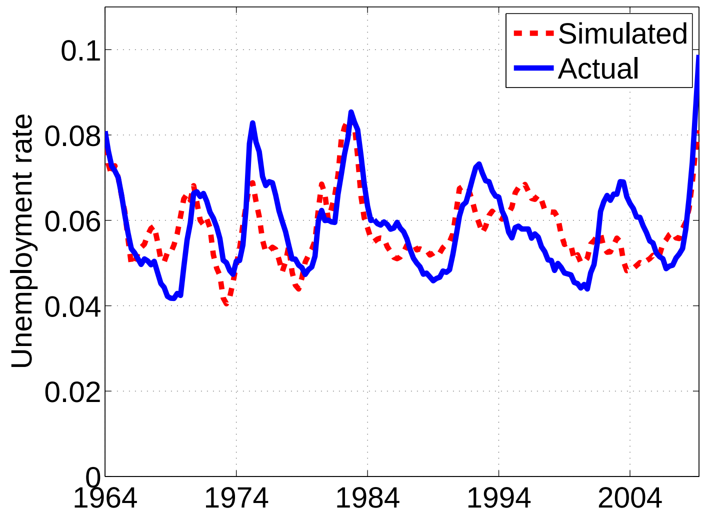

Figure 3: ACTUAL AND SIMULATED U.S. UNEMPLOYMENT, 1964–2009

Notes: Actual unemployment rate is quarterly average of monthly series constructed by the BLS from the CPS. Simulated unemployment rate is generated when the model is stimulated by the quarterly technology series constructed from BLS output and employment data. Actual technology and unemployment are seasonally adjusted and detrended with a HP filter with smoothing parameter 10^5. The time period is 1964:Q1–2009:Q2. I solve the (nonlinear) model with the Fair and Taylor (1983) shooting algorithm.

percent and rationing unemployment climbed to 6.3 percent.[26,27]

Over the period 1964:Q1–2009:Q2, simulated unemployment is 5.8 percent on average; it is mostly composed of frictional unemployment, which averages 3.6 percent; rationing unemployment averages only 2.2 percent. But rationing unemployment is twice as volatile as frictional unemployment; quarterly simulated standard deviations are 0.016 and 0.008 respectively. I also verify with this simulation that inefficient job separations never occur during the entire sample period: hiring always remains positive.

[26]Technology is not adjusted for variable factor utilization. Therefore, fluctuations of measured technology could be partly endogenous. The Appendix addresses this issue by simulating another series for unemployment using the quarterly, utilization-adjusted total factor productivity series (TFP) from Fernald (2009) as driving force. This TFP series accounts for labor hoarding and variable capital utilization. The fit of the model remains good, and the decomposition is very similar to that obtained with technology as driving force. These results confirm the robustness of my quantitative finding that fluctuations in the composition of unemployment are large at business cycle frequency.

[27]The Appendix approaches the decomposition from another angle. I determine the technology series such that model-generated unemployment exactly matches actual unemployment, and construct rationing and frictional unemployment rates from this series. This alternative decomposition confirms the quantitative findings.

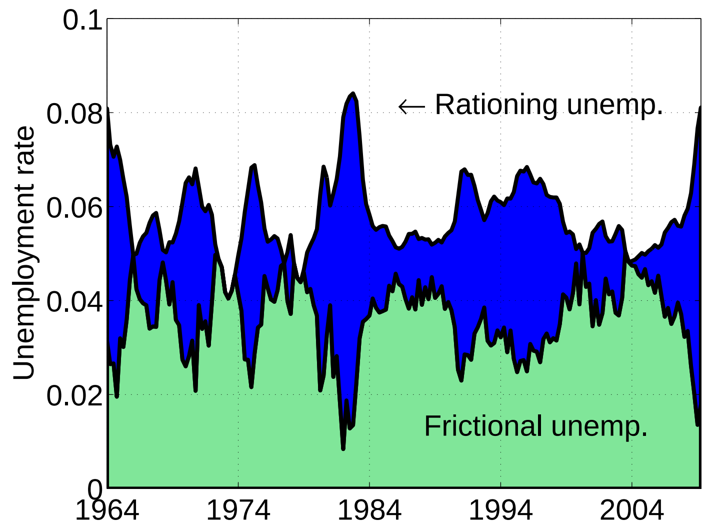

Figure 4: DECOMPOSITION OF SIMULATED U.S. UNEMPLOYMENT, 1964–2009

Notes: The graph decomposes the unemployment series generated when the (nonlinear) model is stimulated by the quarterly technology series constructed from BLS output and employment data. Technology is seasonally adjusted and detrended with a HP filter with smoothing parameter 10^5. The period is 1964:Q1–2009:Q2. I solve the model with the Fair and Taylor (1983) shooting algorithm. Frictional and rationing unemployment are constructed from (16) and (17).

6 Concluding Remarks

6.1 Summary

This paper develops a tractable model of the labor market in which unemployment stems from matching frictions and job rationing. Real wage rigidity and diminishing marginal returns to labor give rise to job rationing in an economic equilibrium. The paper assesses the contribution of each of these two sources to cyclical fluctuations in unemployment. The picture of recessions that emerges in this analysis is one where falling technology leads to an acute shortage of jobs. This shortage drives an increase in total unemployment. Simultaneously, the amount of additional unemployment attributable to matching frictions falls because it becomes easier for firms to recruit.

6.2 Relation to the macroeconomic literature on unemployment

This paper bridges the gap between two important but separate bodies of research: the search-and-matching literature, and the job-rationing literature. The search-and-matching model developed in Mortensen and Pissarides (1994) and Pissarides (2000) has become the standard theory of equilibrium unemployment. It is an attractive framework to understand the relation between unemployment and labor market flows. But recent literature highlights its shortcomings in explaining periods of high unemployment (Shimer 2005). The job-rationing literature offers an alternative account of unemployment based on the premise that wages may be above market-clearing level leading to a shortage of jobs, such as in efficiency-wage models (Solow 1979; Stiglitz 1976), gift-exchange models (Akerlof 1982), insider-outsider models (Lindbeck and Snower 1988), and social-norm models (Akerlof 1980). Although these models contribute to our understanding of periods of high unemployment, they were not successfully integrated in the prevalent macroeconomic model.

This paper departs significantly from the search-and-matching literature, in which the labor market clears in the absence of matching frictions. In my model the labor market may not clear in equilibrium even when recruiting cost is zero, because there is no mechanism to bring wages down to market-clearing level. Since firms meet job applicants one at a time, sequentially, they cannot auction off jobs as in the perfectly competitive setting.

The integration of matching frictions and job rationing offers a unifying treatment of unemployment, which accounts for labor market flows, costly matching, and a possible shortage of jobs resulting from a failure of the labor market to clear even in the absence of matching frictions. Importantly, the two sources of unemployment are introduced in an economic equilibrium: wages never trigger the inefficient dissolution of a worker-firm pair generating a positive bilateral surplus. This paper shows that unemployment is best described as a combination of frictional and rationing unemployment. Search-and-matching theory describes the labor market well in normal and good times; job-rationing theory describes it well in bad times; but only their integration adequately explains unemployment over the entire business cycle.

6.3 Normative implications

How we model unemployment—as the result of matching frictions or as a lack of jobs—has important normative consequences. The two sources of unemployment engender different welfare costs and warrant different unemployment policies. My description of fluctuations in the components of unemployment therefore has novel policy implications.

The MP model usually predicts small welfare costs of unemployment. Unemployment is even optimal under Hosios (1990) condition. When distortions such as rigid wages are introduced (as in the MPR model), unemployment may be inefficiently high but improving matching on the labor market effectively reduces unemployment in models that abstract from job rationing. Additionally in models in which matching frictions are the sole source of unemployment, policies providing disincentives for unemployed workers to exert search effort, such as generous unemployment insurance, always trigger large increases in aggregate unemployment.

This paper offers a more nuanced theory of unemployment in which matching frictions are the most important source of unemployment in expansions, and job rationing is the most important source of unemployment in recessions. Job rationing generates unemployment that is pure waste from a social point of view because unemployed workers who are willing to work at a wage below the market wage cannot find a job; unlike in the MP model, their being unemployed is not justified by the presence of matching frictions.[28] This theory has several normative implications. Unemployment may be very costly in recessions. Policies should be directed at improving matching in periods of moderate unemployment, and creating jobs in periods of high unemployment. A generous unemployment insurance, which reduces the search effort of unemployed workers, increases unemployment significantly only in expansions, but not in recessions. Hence, unemployment insurance should be lower in expansions to provide incentives to search for jobs and reduce aggregate unemployment; it should be higher in recessions to provide better insurance at little cost on aggregate unemployment.

[28] In a MP model satisfying Hosios (1990) condition, unemployment is socially optimal because the presence of unemployed workers searching for a job reduces the amount of resources spent on recruiting, and increases the amount of resources allocated to consumption.

6.4 Directions for future research

This paper is a first attempt at providing a unified framework to study unemployment, and it has limitations that must be addressed in the future. The rigid wage schedule specified in my model is both theoretically and empirically valid, but it does not explain where wage rigidity comes from. Empirical observations suggest that wage rigidity is a reality of the labor market. Yet it cannot be generated by standard wage-setting mechanisms.[29] An important research agenda is to design a wage-setting mechanism explaining the wage rigidity observed in the data to improve our understanding of job rationing and unemployment fluctuations. Second, flows out of employment, in particular layoffs, seem to be quite countercyclical (Elsby et al. 2009). My model abstracts from this issue and assumes a constant rate of job destruction. Understanding job destructions (both layoffs and voluntary quits) and their interaction with job rationing is a topic for future research. Third, the model is simplistic in that there are only technology shocks. There is growing evidence that other shocks also perturb the labor market, and future work should explore how demand shocks or financial disturbances affect the behavior of unemployment and its components.

[29]While microfounded models of wage rigidity have been developed, they remain too complex to be analytically tractable in macroeconomic models (for example, Rudanko 2009).

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A Proofs

Proof of Propositions 1, 2, and 3. Equilibrium condition (8) uniquely defines θ as an implicit function of c in a static environment in the MP model. Assume that $\exists L \geq 0$, $\theta < L$ for all $c > 0$. As $1/q(\cdot)$ increases in θ,

$$0 < \left\{[1-\delta\cdot(1-s)]\frac{1}{q(\theta)} + \delta\cdot(1-s)\cdot\beta\cdot\theta\right\} < \left\{[1-\delta\cdot(1-s)]\frac{1}{q(L)} + \delta\cdot(1-s)\cdot\beta\cdot L\right\} \equiv \lambda.$$

For $0 < c < \frac{1}{\lambda}\cdot(1-\beta)$, condition (8) cannot hold; thus $\lim_{c\to 0}\theta(c) = +\infty$. Equation (3) implies $\lim_{c\to 0} N(c) = 1$. A similar argument allows me to prove Proposition 2, using equilibrium condition (9) and the fact that equation (3) defines N as an increasing function of θ. A similar argument allows me to prove Proposition 3, using equilibrium condition (10). □

Proof of Proposition 4. Obvious using equilibrium condition (11), as well as the continuity of all functions involved. □

Proof of Proposition 5. Equation (11) yields $\partial N/\partial a > 0$ and $\partial\theta/\partial a > 0$. When $a \in (0, a^R)$, equation (13) yields $\partial N^R/\partial a < 0$. Using (13) and defining $N^F \equiv N^R - N$, I can rewrite (11) as

$$\alpha\cdot\left\{N^{\alpha-1} - \left(N^R\right)^{\alpha-1}\right\} = [1-(1-s)\cdot\delta]\cdot\frac{c}{q(\theta)}$$
$$\alpha\cdot(1-\alpha)\int_0^{N^F}\left(N^R-n\right)^{\alpha-2}dn = [1-(1-s)\cdot\delta]\cdot\frac{c}{q(\theta)}.$$

Differentiating the last line with respect to a yields

$$\left\{\alpha\cdot(1-\alpha)\cdot(2-\alpha)\int_0^{N^F}\frac{\partial N^R}{\partial a}\cdot\left(N^R-n\right)^{\alpha-3}dn\right\} + \left\{\alpha\cdot(1-\alpha)\cdot\frac{\partial N^F}{\partial a}\cdot N^{\alpha-2}\right\}$$
$$= -c\cdot[1-(1-s)\cdot\delta]\cdot\frac{\partial q}{\partial\theta}\cdot\frac{1}{q(\theta)^2}\cdot\frac{\partial\theta}{\partial a}.$$

Using the comparative statics above and $\partial q/\partial\theta < 0$, I infer $\partial N^F/\partial a > 0$. To conclude, it suffices to notice that $U(a) = 1-(1-s)\cdot N(a)$, $U^F(a) = s\cdot N(a) + N^F(a)$, and $U^R(a) = 1 - N^R(a)$.

□

B Other Proofs

Proof of Lemma 1. Let $\mathbb{L}_t$ denote the value to the representative household of having a marginal member employed after the matching process in period t, expressed in consumption units. Let $\mathbb{U}_t$

denote the value to the representative household of having a marginal member unemployed.

$$\begin{aligned}\mathbb{L}_t &= W_t + \delta \cdot \mathbb{E}_t \left[\{1 - s \cdot (1 - f(\theta_{t+1}))\} \mathbb{L}_{t+1} + s \cdot (1 - f(\theta_{t+1})) \cdot \mathbb{U}_{t+1} \right] \\ \mathbb{U}_t &= \delta \cdot \mathbb{E}_t \left[(1 - f(\theta_{t+1})) \cdot \mathbb{U}_{t+1} + f(\theta_{t+1}) \cdot \mathbb{L}_{t+1} \right].\end{aligned}$$

These continuation values are the sum of current payoffs, plus the discounted expected continuation values. Combining both conditions yields the household's surplus from an established job relationship:

$$\mathbb{L}_t - \mathbb{U}_t = W_t + \delta \cdot \mathbb{E}_t \left[(1 - s) \cdot (1 - f(\theta_{t+1})) \cdot (\mathbb{L}_{t+1} - \mathbb{U}_{t+1}) \right].$$

In this setting, the firm's surplus from an established relationship is simply given by the hiring cost $c \cdot a_t / q(\theta_t)$, since a firm can immediately replace a worker at that cost during the matching period. Assume that wages are continually renegotiated. Since the bargaining solution divides the surplus of the match between the worker and firm with the worker keeping a fraction $\beta \in (0, 1)$ of the surplus, the worker's surplus each period is related to the firm's surplus:

$$\mathbb{L}_t - \mathbb{U}_t = \frac{\beta}{1 - \beta} \cdot \frac{c \cdot a_t}{q(\theta_t)}.$$

Thus, the solution of the bargaining game is

$$W_t = c \cdot \frac{\beta}{1 - \beta} \cdot \left\{ \frac{a_t}{q(\theta_t)} - \delta \cdot (1 - s) \cdot \mathbb{E}_t \left[\left(\frac{1}{q(\theta_{t+1})} - \theta_{t+1} \right) \cdot a_{t+1} \right] \right\}.$$

□

Proof of Lemma 2. The wage schedule $W(N_t)$ is determined by Nash bargaining over the marginal surplus from a match. To simplify, I assume that the wage that solves the bargaining problem does not generate layoffs. I verify at the end of the derivation that the solution actually satisfies this condition. As in the proof of Lemma 1, the surplus to the representative household of having a marginal member employed in an established job relationship is:

$$\mathbb{L}_t - \mathbb{U}_t = W_t + \delta \cdot \mathbb{E}_t \left[(1 - s) \cdot (1 - f(\theta_{t+1})) \cdot (\mathbb{L}_{t+1} - \mathbb{U}_{t+1}) \right]. \tag{A1}$$

Following the derivations in Section 2, the marginal profit to the firm of having an additional worker, once the relationship is established, is

$$\mathbb{J}_t = \frac{\partial F}{\partial N} - W_t - N_t \cdot \frac{\partial W}{\partial N} + (1 - s) \cdot \delta \cdot \mathbb{E}_t \left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})} \right]. \tag{A2}$$

This marginal profit corresponds to the surplus of the established relationship accruing to the firm. Note that the firm maximizes profit taking the wage rule as given, and that the first-order condition (7) implies that

$$\mathbb{J}_t = \frac{c \cdot a_t}{q(\theta_t)}. \tag{A3}$$

Since the bargaining solution divides the surplus of the match between the worker and firm with the worker keeping a fraction $\beta \in (0,1)$ of the surplus, the worker's marginal surplus each period is related to the firm's marginal surplus:

$$\mathbb{L}_t - \mathbb{U}_t = \frac{\beta}{1-\beta} \cdot \mathbb{J}_t. \tag{A4}$$

Combining (A1)-(A4), I can derive a differential equation in the wage schedule:

$$W(N_t) + \beta \cdot N_t \cdot \frac{\partial W}{\partial N} = \beta \left[\frac{\partial F}{\partial N} + c \cdot (1-s) \cdot \delta \cdot \mathbb{E}_t \left[a_{t+1} \cdot \theta_{t+1} \right] \right].$$

With $F(N_t, a_t) = a_t N_t^{\alpha}$, the solution of the above equation is

$$W(N_t) = \beta \cdot \left[\frac{\alpha \cdot a_t \cdot N_t^{\alpha-1}}{1-\beta(1-\alpha)} + c \cdot (1-s) \cdot \delta \cdot \mathbb{E}_t \left[a_{t+1} \cdot \theta_{t+1} \right] \right].$$

□

Proof of Lemma 3. I determine a condition on the stochastic process for technology, as well as the parameters of the model, such that endogenous layoffs do not occur. A firm's optimal hiring behavior is detailed in Lemma A1.

LEMMA A1. *Let the marginal revenue $\hat{\nu}_t(i)$ be defined by*

$$\hat{\nu}_t(i) = \frac{\partial F}{\partial N} \left((1-s) \cdot N_{t-1}(i), a_t \right).$$

There exist marginal costs $\nu_t^H(i) > \nu_t^L(i)$ such that:

(i) if $\hat{\nu}_t(i) < \nu_t^L(i)$, firm i lays workers off;

(ii) if $\hat{\nu}_t(i) \in [\nu_t^L(i), \nu_t^H(i)]$, firm i freezes hiring;

(iii) if $\hat{\nu}_t(i) > \nu_t^H(i)$, firm i hires workers.

Proof. The Lagrangian for firm i's problem, which accounts for possible layoffs, is

$$\begin{aligned} L = & \mathbb{E}_0 \sum_{t \geq 0} \delta^t \cdot \{ F(N_t(i), a_t) - N_t(i) \cdot W_t(i) \\ & - \mathbf{1}\{ N_t(i) > (1-s) N_{t-1}(i) \} \cdot \frac{c \cdot a_t}{q(\theta_t)} \cdot [N_t(i) - (1-s) N_{t-1}(i)] \Big\}. \end{aligned}$$

The firm's problem is a concave maximization problem, so it admits a unique solution determined by the first-order conditions. The highest marginal revenue that firm i can obtain in period t without laying workers off is

$$\hat{\nu}_t(i) = \frac{\partial F}{\partial N}\left((1-s)\cdot N_{t-1}(i), a_t\right).$$

Next, I define the following marginal costs $\forall\, t \geq 0$:

$$\begin{aligned}
\nu_t^L(i) =& \frac{W_t(i) - \delta \cdot \mathbb{E}_t\left[\partial L_{t+1}/\partial N_t\right]}{\partial F/\partial N((1-s)N_{t-1}(i), a_t)} \\
\nu_t^H(i) =& \frac{W_t(i) + c \cdot a_t/q(\theta_t) - \delta \cdot \mathbb{E}_t\left[\partial L_{t+1}/\partial N_t\right]}{\partial F/\partial N((1-s)N_{t-1}(i), a_t)},
\end{aligned}$$

where I define $\forall\, t \geq 0$:

$$\begin{aligned}
L_{t+1} = \sum_{\tau \geq t+1} \delta^{\tau-(t+1)} \cdot \Big\{ & F(N_\tau(i), a_\tau) - N_\tau(i) \cdot W_t(i) \\
& - \mathbf{1}\left\{N_\tau(i) > (1-s)N_{\tau-1}(i)\right\} \cdot \frac{c \cdot a_\tau}{q(\theta_\tau)} \cdot \left[N_\tau(i) - (1-s)N_{\tau-1}(i)\right] \Big\}.
\end{aligned}$$

Computing $\nu_t^L(i)$ and $\nu_t^H(i)$ requires computing $\mathbb{E}_t\left[\partial L_{t+1}/\partial N_t\right]$. Let $\mathcal{F}$ be the $\sigma-$algebra generated by future realizations of the stochastic process $\{a_\tau, \tau \geq t+1\}$, taking as given the information set at time t. I partition $\mathcal{F}$ as follows:

$$\mathcal{F} = \mathcal{F}^+ \cup \mathcal{F}^- \cup_{h=1}^{+\infty} \mathcal{F}^h. \tag{A5}$$

$\mathcal{F}^+$ is the subset of future realizations of $\{a_t\}$ such that there is hiring next period. $\mathcal{F}^-$ is the subset such that there are layoffs next period. Last, for $h \geq 1$, $\mathcal{F}^h$ is the subset such that there is a hiring freeze for the h next periods. Let $p^+ = \mathbb{P}(\mathcal{F}^+)$, $p^- = \mathbb{P}(\mathcal{F}^-)$, and $p^h = \mathbb{P}(\mathcal{F}^h)$ be the measure of these subsets. Using the law of total probability over this partition:

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

It is easy to show that:

$$\begin{aligned}
\mathbb{E}_t\left[\partial L_{t+1}/\partial N_t | \mathcal{F}^+\right] =& (1-s) \cdot \mathbb{E}_t\left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})} | \mathcal{F}^+\right] \\
\mathbb{E}_t\left[\partial L_{t+1}/\partial N_t | \mathcal{F}^-\right] =& 0 \\
\mathbb{E}_t\left[\partial L_{t+1}/\partial N_t | \mathcal{F}^h\right] =& \mathbb{E}_t\Bigg[\sum_{j=t+1}^{t+h} \delta^{j-(t+1)} \cdot (1-s)^{j-t} \cdot \Big\{\partial F/\partial N((1-s)^{j-t} \cdot N_t(i), a_j) \\
& - W_j\Big\} + (1-s)^{h+1} \cdot \frac{c \cdot a_{t+h+1}}{q(\theta_{t+h+1})} | \mathcal{F}^h\Bigg].
\end{aligned}$$

$\nu_t^L(i)$ and $\nu_t^H(i)$ are well defined, and depend on the stochastic process $\{\theta_\tau, \tau \geq t+1\}$, as well as on employment at the beginning of period t: $(1-s)N_{t-1}(i)$. I assume that marginal cost is strictly increasing in $N_t(i)$, so that the firm's optimization has a unique solution (the marginal profit function strictly decreases with $N_t(i)$). $\nu_t^L(i)$ is the lowest marginal cost that the firm can achieve by keeping all its workforce. This is achieved by freezing hiring. $\nu_t^H(i) > \nu_t^L(i)$ is the lowest marginal cost the firm can achieve, while recruiting workers. It is achieved by recruiting an infinitely small amount of workers. Then, the optimal decision of the firm is obtained by comparing $\nu_t^L(i), \nu_t^H(i)$, and $\hat{\nu}_t(i)$. The optimal decision of a monopolist is characterized by the equality of marginal costs and marginal revenues. If $\hat{\nu}_t(i) < \nu_t^L(i)$, firm i must reduce its workforce to increase its gross marginal profit and reduce its marginal costs, which implies layoffs. Conversely, if $\hat{\nu}_t(i) > \nu_t^H(i)$, firm i must hire more workers to reduce its gross marginal profit and increase its marginal cost until both are equal. If $\hat{\nu}_t(i) \in [\nu_t^L(i), \nu_t^H(i)]$, firm i optimally freezes hiring.

□

In a symmetric environment, if a firm freezes hiring, all firms do so, $\theta_t = 0$, $c \cdot a_t / q(\theta_t) = 0$, and for all i, $\nu_t^L(i) = \nu_t^H(i)$. This means that hiring freezes occur with probability 0. Either all firms recruit, or they all lay workers off. Using Lemma A1 and its proof, we know that in a symmetric environment a necessary and sufficient condition to avoid layoffs in period t is $\hat{\nu}_t \geq \nu_t^H$. Moreover, $\mathbb{E}_t\left[c \cdot a_{t+1}/q(\theta_{t+1})\right] = \mathbb{E}_t\left[c \cdot a_{t+1}/q(\theta_{t+1}) | \mathcal{F}^+\right] \cdot p^+$ because $\mathbb{E}_t\left[c \cdot a_{t+1}/q(\theta_{t+1}) | \mathcal{F}^-\right] = 0$, and $p^h = 0$ for all h, using the partition defined by (A5). Therefore

$$\mathbb{E}_t\left[\partial L_{t+1}/\partial N_t\right] = \mathbb{E}_t\left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})} | \mathcal{F}^+\right] \cdot p^+ = \mathbb{E}_t\left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})}\right].$$

Accordingly, a necessary and sufficient condition to avoid layoffs is $\forall t \geq 0$,

$$\frac{\partial F}{\partial N}((1-s) \cdot N_{t-1}, a_t) \geq W_t - \delta \cdot (1-s) \cdot \mathbb{E}_t\left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})}\right].$$

Using the specifications given by Assumptions 5 and 3, the condition becomes

$$\alpha \cdot a_t \cdot [(1-s) \cdot N_{t-1}]^{\alpha-1} \geq w_0 \cdot a_t^{\gamma} - \delta \cdot (1-s) \cdot \mathbb{E}_t\left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})}\right].$$

Since $\mathbb{E}_t\left[\frac{c \cdot a_{t+1}}{q(\theta_{t+1})}\right] \geq 0$, a sufficient condition to avoid endogenous layoffs is:

$$\frac{\alpha}{w_0}(1-s)^{\alpha-1} \cdot N_{t-1}^{\alpha-1} \geq a_t^{\gamma-1}. \tag{A6}$$

The Euler equation in period $t-1$ in a symmetric equilibrium is

$$\alpha \cdot a_{t-1} \cdot N_{t-1}^{\alpha-1} = w_0 \cdot a_{t-1}^{\gamma} + \frac{c \cdot a_{t-1}}{q(\theta_{t-1})} - \delta \cdot (1-s) \cdot \mathbb{E}_{t-1}\left[\frac{c \cdot a_t}{q(\theta_t)}\right].$$

I assume that the fluctuations in technology are small enough such that for all $t-1$

$$\frac{c \cdot a_{t-1}}{q(\theta_{t-1})} - \delta \cdot (1-s) \cdot \mathbb{E}_{t-1}\left[\frac{c \cdot a_t}{q(\theta_t)}\right] \geq 0.$$

This is equivalent to imposing that frictional unemployment always be positive. As shown in Figure 4, this is verified in practice. Under this technical assumption,

$$\alpha \cdot a_{t-1} \cdot N_{t-1}^{\alpha-1} \geq w_0 \cdot a_{t-1}^{\gamma}. \tag{A7}$$

Plugging (A7) into (A6) yields the following sufficient condition to avoid layoffs:

$$(1-s)^{\alpha-1} \geq \left(\frac{a_{t-1}}{a_t}\right)^{1-\gamma}$$
$$(\alpha-1) \cdot \log(1-s) \geq (1-\gamma) \cdot [\log(a_{t-1}) - \log(a_t)]$$

Using $\log(a_t) = \log(a_{t-1}) + z_t$, I find a sufficient condition on the technology shock in period t to avoid layoffs is:

$$z_t \geq \frac{1-\alpha}{1-\gamma} \cdot \log(1-s)$$

Let $\Phi(\cdot)$ be the cumulative distribution function of the $N(0,1)$ distribution. Given that z_t is normally distributed with variance σ^2, I infer that layoffs occur with probability below

$$\Phi\left(\frac{1}{\sigma} \cdot \left[\frac{1-\alpha}{1-\gamma} \cdot \log(1-s)\right]\right).$$

Conversely, if we want layoffs to occur with a probability below p, it is sufficient that the wage flexibility γ verifies

$$\gamma \geq 1 - (1-\alpha) \cdot \frac{\log(1-s)}{\sigma \cdot \Phi^{-1}(p)}$$

□

C Log-Linearized Model

I first characterize the steady state of the model, and then describe the log-linearized equilibrium conditions around this steady state. $\bar{x}$ denotes the steady-state value of variable X_t. The symmetric steady-state equilibrium $\{\overline{c},\overline{n},\overline{y},\overline{h},\overline{\theta},\overline{u},\overline{w}\}$ is characterized by the following equations:

$$\begin{aligned}
\overline{u} =& \frac{s}{s+(1-s)\cdot f(\overline{\theta})} \\
\overline{n} =& \frac{1-\overline{u}}{1-s} \\
\overline{h} =& s\cdot\overline{n} \\
\overline{y} =& \overline{a}\cdot\overline{n}^{\alpha} \\
\overline{c} =& \overline{y} - \frac{c\cdot\overline{a}}{q(\overline{\theta})}\cdot\overline{h} \\
\overline{w} =& w_0 \\
0 =& \alpha\cdot\overline{n}^{\alpha-1} - \overline{w} - [1-\delta\cdot(1-s)]\,\frac{c\cdot\overline{a}}{q(\overline{\theta})} \\
\overline{a} =& 1
\end{aligned}$$

$\check{x}_t \equiv d\log(X_t)$ denotes the logarithmic deviation of variable X_t. The equilibrium is described by the following system of log-linearized equations:

- Definition of labor market tightness:

$$(1-\eta)\cdot\check{\theta}_t = \check{h}_t - \check{u}_{t-1}$$

- Definition of unemployment:

$$\check{u}_{t-1} + \frac{1-\overline{u}}{\overline{u}}\cdot\check{n}_{t-1} = 0$$

- Law of motion of employment:

$$\check{n}_t = (1-s)\cdot\check{n}_{t-1} + s\cdot\check{h}_t$$

- Resource constraint:

$$\check{y}_t = (1-s_1)\cdot\check{c}_t + s_1\cdot\left(\check{h}_t + \eta\cdot\check{\theta}_t + \check{a}_t\right),$$

  with $s_1 = \dfrac{c}{q(\overline{\theta})}\cdot s\cdot\overline{n}^{1-\alpha}$.

- Production constraint:

$$\check{y}_t = \check{a}_t + \alpha\cdot\check{n}_t$$

- Wage rule:

$$\check{w}_t = \gamma\cdot\check{a}_t$$

- Firm's Euler equation:

$$-\check{a}_t + (1-\alpha)\cdot\check{n}_t + s_2\cdot\check{w}_t + s_3\cdot\left(\eta\cdot\check{\theta}_t + \check{a}_t\right) + (1-s_2-s_3)\mathbb{E}_t\left[\eta\cdot\check{\theta}_{t+1} + \check{a}_{t+1}\right] = 0$$

Table 4: PARAMETER VALUES USED IN SIMULATIONS OF BENCHMARK MODELS.

	Interpretation	Value	Source
MP model:			
c	Recruiting cost	0.32	$0.32 \times \overline{w}$
β	Worker's bargaining power	0.86	Matches unemployment $= 5.8\%$
MPR model:			
c	Recruiting cost	0.32	$0.32 \times \overline{w}$
w_0	Steady-state real wage	0.991	Matches unemployment $= 5.8\%$
SZ model:			
c	Recruiting cost	0.22	$0.32 \times \overline{w}$
α	Returns to labor	0.21	Matches labor share$= 0.66$
β	Worker's bargaining power	0.86	Matches unemployment $= 5.8\%$

Notes: All parameters are calibrated at weekly frequency.

with $s_2 = \overline{w} \cdot \frac{1}{\alpha \cdot \overline{a}} \cdot \overline{n}^{1-\alpha}$ and $s_3 = \frac{c}{q(\overline{\theta})} \cdot \frac{1}{\alpha} \cdot \overline{n}^{1-\alpha}$.

- Productivity shock:

$$\check{a}_t = \rho \cdot \check{a}_{t-1} + z_t$$

D Calibration of Various Search-and-Matching Models

I follow the same calibration strategy as in Section 5. All calibrated parameters are summarized in Table 4.

D.1 Calibration of the MP model

In steady-state, since $c = 0.32 \times \overline{w}$:

$$\frac{1-\delta(1-s)}{q(\overline{\theta})} = \frac{1-\overline{w}}{0.32 \times \overline{w}}.$$

I target $\overline{u} = 5.8\%$, or equivalently $\overline{\theta} = 0.45$. This pins down $\overline{w} = 0.990$, and $c = 0.32$. Then, in steady state

$$\frac{1-\delta \cdot (1-s)}{q(\overline{\theta})} + \beta \cdot \delta \cdot (1-s)\overline{\theta} = (1-\beta)\frac{1}{c},$$

which pins down the bargaining power $\beta = 0.86$.

D.2 Calibration of the MPR model

In steady-state, $\overline{w} = w_0$ and $c = 0.32 \times \overline{w}$, so

$$\frac{1-\delta(1-s)}{q(\overline{\theta})} = \frac{1-w_0}{0.32 \times w_0}.$$

I target $\overline{u} = 5.8\%$, or equivalently $\overline{\theta} = 0.45$. This pins down $w_0 = 0.990$, and $c = 0.32$.

D.3 Calibration of the SZ model

Let $\kappa = \dfrac{\alpha}{1-\beta\cdot(1-\alpha)}$. The steady-state wage equation, firm's Euler equation, and definition of the labor share are

$$\overline{w} = \beta\left[\kappa\cdot\overline{n}^{\alpha-1} + c\cdot(1-s)\cdot\delta\cdot\overline{\theta}\right] \tag{A8}$$

$$(1-\beta)\cdot\kappa\cdot\overline{n}^{\alpha-1} = [1-\delta(1-s)]\frac{c}{q(\overline{\theta})} + c\cdot(1-s)\cdot\delta\cdot\beta\cdot\overline{\theta} \tag{A9}$$

$$\overline{ls} = \overline{w}\cdot\overline{n}^{1-\alpha}. \tag{A10}$$

Combining (A8), (A9), and (A10), and using $c = 0.32 \times \overline{w}$ yields:

$$\kappa = \left[(1-\delta\cdot(1-s))\frac{0.32}{q(\overline{\theta})} + 1\right]\overline{ls} \tag{A11}$$

$$\overline{ls} = \overline{w}\cdot\overline{n}^{1-\alpha} \tag{A12}$$

$$\overline{w} = \beta\left[\kappa\cdot\overline{n}^{\alpha-1} + c\cdot(1-s)\cdot\delta\cdot\overline{\theta}\right]. \tag{A13}$$

Equation (A11) identifies $\kappa = 0.67$, given that I target $\overline{ls} = 0.66$ and $\overline{\theta} = 0.45$. Equation (A12) then determines $\overline{w} = 69$, given that I target $\overline{n} = 0.95$. Finally, (A13) determines $\beta = 0.86$. I can then calculate $\alpha = \dfrac{\kappa - \kappa\beta}{1-\kappa\beta} = 0.21$.

E Comparison of Different Numerical Solution Methods

Figure 5 compares the time series for unemployment and labor market tightness generated by the model with two different numerical solution methods: (i) a series of equilibria in static environments that abstract from aggregate shocks to technology and dynamics of unemployment; and (ii) the exact solution to the nonlinear model, which accounts fully both for the dynamics of unemployment and rational expectations of stochastic process of technology and labor market variables.

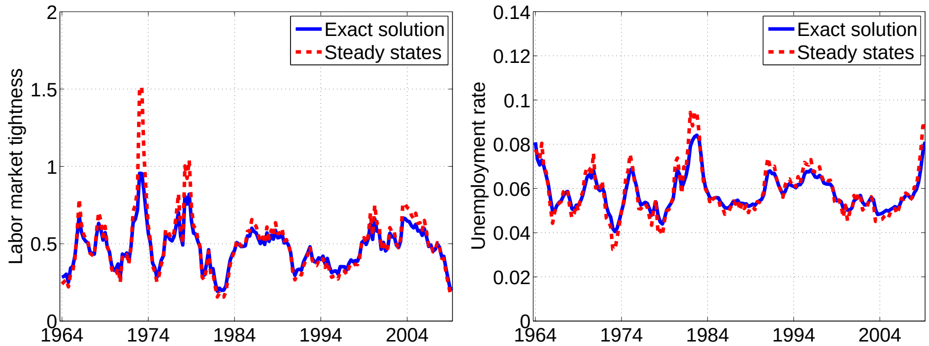

Figure 5: Labor market tightness and unemployment across solution methods.

The series of equilibria in static environments is obtained by solving the system of equations (1), (3), and (11) to determine employment N, unemployment U, and labor market tightness θ for each realization of technology a. I then plot the series of steady-state unemployment and labor market tightness corresponding to the series of realization of technology.

The exact solution to the model is obtained by using the Fair and Taylor (1983) shooting algorithm. This algorithm solves dynamic rational expectation models period by period, by iterating in each period over the path of expected values for endogenous (employment and labor market tightness) and exogenous (technology) variables, until this path converges from an arbitrary path to a path of rational expectations, consistent with the predictions of the model.

While the time series obtained with these two numerical solution methods are quantitatively different, they are qualitatively similar. The main difference between these two labor market tightness series is that θ_t spikes and plummets more drastically with the steady-state solution method. This is because after a positive technology shock, firms do not take into account the fact that technology will eventually revert to a lower, mean value, making recruiting less profitable. Therefore, firms are predicted to recruit too much in the steady-state solution method after a positive shock. For the same reason, firms are predicted to recruit too little after a negative shock, because they do not expect that technology will eventually revert to a higher, mean value. This discrepancy in the predicted recruiting behavior of firms also affects predicted unemployment, but the difference between the two series is relatively small. To conclude, solving the model without accounting for aggregate shocks offers a good approximation to the exact solution.

F Quantitative Analysis With Capacity-Adjusted TFP Series

Technology is not adjusted for variable factor utilization. Therefore, fluctuations in technology may be partly endogenous. To address this issue, I construct another series of model-generated unemployment using the quarterly, utilization-adjusted total factor productivity series (TFP) from Fernald (2009) as the model driving force. Actual and model-generated unemployment are shown on the bottom graph in Figure 6. The fit of the model remains good.

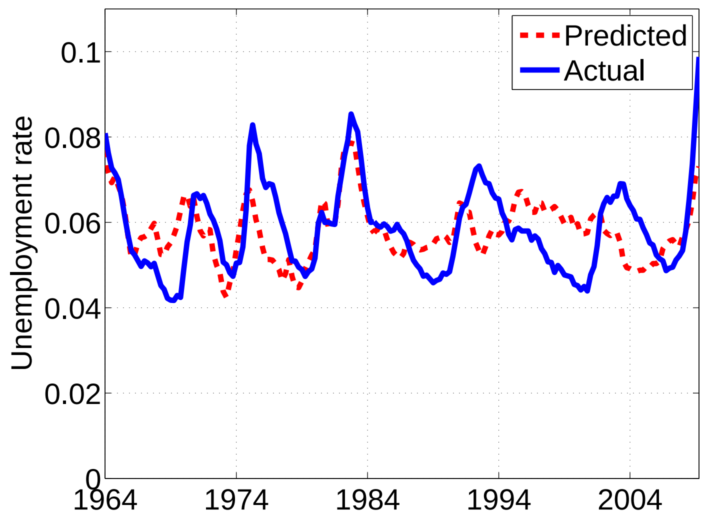

Figure 6: ACTUAL UNEMPLOYMENT, AND UNEMPLOYMENT GENERATED FROM ACTUAL TFP MEASURED IN U.S. DATA, 1964–2009.

Notes: Actual unemployment is the quarterly average of seasonally-adjusted monthly series constructed by the BLS from the CPS. Model-generated unemployment series generated when the model is stimulated by the quarterly, utilization-adjusted TFP series constructed by Fernald (2009). ActualTFP and unemployment are detrended with a HP filter with smoothing parameter 10^5. The time period is 1964:Q1–2009:Q2. I solve the (nonlinear) model with the Fair and Taylor (1983) shooting algorithm.

I also repeat the decomposition exercise using utilization-adjusted TFP series. The decomposition is presented on Figure 7 and appears to be very similar to that obtained with technology as driving force. This new result confirms the robustness of my quantitative finding that fluctuations in the composition of unemployment are large at business cycle frequency.

G Another Historical Decomposition of Unemployment

In this section, I approach the decomposition exercise presented in Section 5 from another angle. I decompose actual U.S. unemployment into rationing and frictional series instead of decomposing model-generated unemployment. To do so, I need to uncover the time series for technology that would generate observed unemployment with my model. Of course, this model-generated technology does not exactly match actual technology, just as model-generated unemployment cannot match actual unemployment if I stimulate the model with actual technology.

To uncover the technology series, I assume that unemployment is a function of labor market tightness at any time

$$U_t = \frac{s}{s + (1-s) \cdot f(\theta_t)}. \tag{A14}$$

This approximation is motivated by the observation that rates of job destruction and job creation

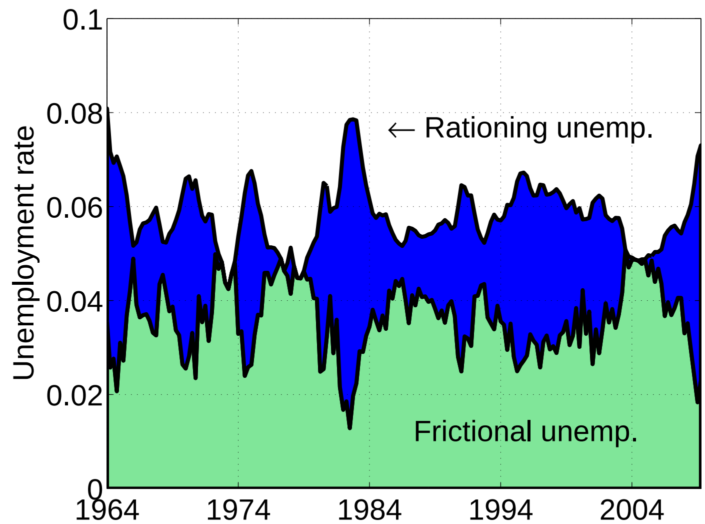

Figure 7: DECOMPOSITION OF UNEMPLOYMENT GENERATED FROM ACTUAL TFP MEASURED IN U.S. DATA, 1964–2009.

Notes: The graph decomposes the unemployment series generated when the (nonlinear) model is stimulated by the quarterly, utilization-adjusted TFP series constructed by Fernald (2009). Actual TFP and unemployment are detrended with an HP filter with smoothing parameter 10^5. The time period is 1964:Q1–2009:Q2. I solve the model with the Fair and Taylor (1983) shooting algorithm. Frictional and rationing unemployment are constructed from (16) and (17).

are very large, while the amplitude of technology shocks is small; thus, unemployment rapidly converges to a stochastic equilibrium in which inflows to and outflows from employment are balanced; hence, the path of stochastic equilibria for unemployment, which satisfies (A14), is a good approximation to the dynamic path of unemployment (Hall 2005b; Rotemberg 2008). I solve the model exactly using a shooting algorithm, and I compare this exact solution to the approximate solution obtained if I assume that (A14) holds at any time. The results are displayed in Figure 8. The two solutions are very similar which confirms (A14) is a good approximation to the actual behavior of unemployment.

Equation (A14), together with the assumption that technology shocks follow a Markov process, allows me to express implicitly equilibrium labor market tightness, employment, and unemployment as a function of the current technology level. Then solving the nonlinear, rational-expectation model boils down to solving a system of nonlinear equations with as many equations as the number of states for technology, which can easily be done numerically. Since each possible realization of technology is associated with a given unemployment rate, I can associate each observation of U.S. unemployment rate to a technology level. By doing so, I determine the technology series such that model-generated unemployment exactly matches actual unemployment, and I construct rationing and frictional unemployment rates from this series.

The decomposition is shown in Figure 9, and is quantitatively similar to that presented in the text in Figure 4. Current events illustrate how the composition of unemployment drastically changes

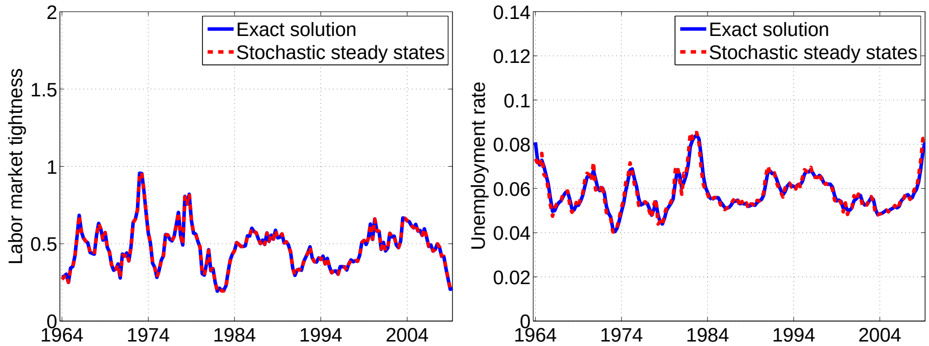

Figure 8: LABOR MARKET TIGHTNESS AND UNEMPLOYMENT ACROSS SOLUTION METHODS.

over the business cycle. In 2007:Q2, actual unemployment was at 4.9 percent, all of which was frictional. In 2008:Q2, actual unemployment was at 5.8 percent, of which 4.3 percent was frictional unemployment and 1.5 percent was rationing unemployment. Finally, in 2009:Q2, actual unemployment reached 9.2 percent, frictional unemployment fell to 1.6 percent, and rationing unemployment increased drastically to 7.6 percent.

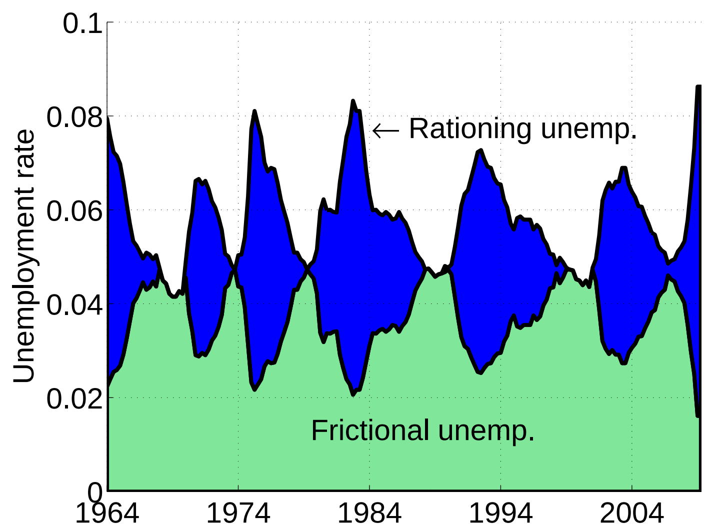

Figure 9: DECOMPOSITION OF ACTUAL U.S. UNEMPLOYMENT, 1964–2009

Notes: The graph decomposes actual unemployment, which is the quarterly average of seasonally-adjusted monthly series constructed by the BLS from the CPS. Actual unemployment is detrended with an HP filter with smoothing parameter 10^5. The time period is 1964:Q1–2009:Q2.

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