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A Model of Unemployment with Matching Frictions and Job Rationing

by

Pascal Michailat

A dissertation submitted in partial satisfaction

of the requirements for the degree of

Doctor of Philosophy

in

Economics

in the

GRADUATE DIVISION

of the

UNIVERSITY OF CALIFORNIA, BERKELEY

Committee in charge:

Professor George Akerlof, Co-chair
Professor Yuriy Gorodnichenko, Co-chair
Professor Matthew Rabin
Professor David Levine

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Pascal Michaillat

Abstract

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Pascal Michailat

Doctor of Philosophy in Economics

University of California, Berkeley

Professor George Akerlof, Co-chair

Professor Yuriy Gorodnichenko, Co-chair

This dissertation proposes a model of the labor market that integrates two important sources of unemployment. The first source is a matching friction, which is a friction in matching unemployed workers to recruiting firms. The second source is job rationing, which is a possible shortage of jobs in the economy. To examine how these two sources interact over the business cycle, I decompose unemployment into a component caused by job rationing—*rationing unemployment*—and another component caused by matching frictions—*frictional unemployment*. Formally, I define rationing unemployment as the level of unemployment that would prevail if matching frictions disappeared, and frictional unemployment as additional unemployment due to the matching frictions.

The main theoretical result of this dissertation is that during recessions rationing unemployment increases, driving the rise in total unemployment, whereas frictional unemployment decreases. Intuitively, in bad times, there are too few jobs, the labor market is slack, recruiting is easy, and matching frictions contribute little to unemployment.

I specify a model in which job rationing stems from a small amount of wage rigidity and diminishing marginal returns to labor. In the model calibrated with U.S. data, I find that when unemployment is below 5%, it is only frictional; but when unemployment reaches 9%, frictional unemployment amounts to less than 2% of the labor force, and rationing unemployment to more than 7%.

I then show that in recessions, job rationing generates inefficiently high unemployment, which leaves room for labor market policies to improve social welfare. I evaluate three labor market policies—direct employment, placement services, and a wage subsidy—over the business cycle. First, I compute state-dependent fiscal multipliers (the increase in social welfare obtained by spending one dollar on a policy) to determine the effectiveness of these unemployment-reducing policies. I prove theoretically that placement services are more

effective in good times than in bad times. The converse is true of direct employment. Intuitively, in bad times, frictional unemployment is low; placement services aim to further reduce this component and are therefore ineffective. The effectiveness of direct employment is a function of how much it crowds private employment out; in bad times, competition for workers is weak and crowding out is limited; thus, this policy is effective. In the calibrated model, wage subsidies are also more effective in bad times than in good times.

To conclude, I characterize the optimal mix of policies implemented by a benevolent social planner. The optimal unemployment-reducing policy evolve over the business cycle: its puts more weight on policy instruments reducing matching frictions (placement services) in good times than in bad times; conversely, it puts more weight on policy instruments creating jobs directly (direct employment and a wage subsidy) in bad times than in good times. Intuitively, the optimal unemployment-reducing policy should adapt to the state of the labor market because of the cyclical fluctuations in the sources of unemployment.

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To my parents, Nicole and François, and to Varanya

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Chapter 1

Introduction

1.1 Research Question

Large fluctuations in unemployment frequently recur across the U.S. and Europe, most recently in 2009, and remain a major concern for policymakers. Many different macroeconomic theories of unemployment have been offered. These theories deliver conflicting results about the welfare cost of unemployment and the impact of various labor market policies, which makes it hard to develop policy recommendations. In fact, there seems to be no consensus on how much governments should spend on unemployment-reducing policies, and which specific policies they should implement. To determine optimal unemployment-reducing policies, it is critical to identify the main sources of unemployment over the business cycle. This is what I attempt to do in this dissertation.

1.2 Methodology

This dissertation proposes a model of the labor market that integrates two important sources of unemployment. The first source is a matching friction, which is a friction in matching unemployed workers to recruiting firms. The second source is job rationing, which is a possible shortage of jobs in the economy. I then study how these two sources interact over the business cycle to shed new light on the mechanics of unemployment fluctuations and the role for unemployment-reducing labor market policies.

The focus on these sources of unemployment is motivated by two observations. First, labor markets see constant job destruction and job creation, as well as large flows of workers (Blanchard and Diamond 1989, Davis et al. 1996). So frictions constantly hindering matching of workers and firms are bound to influence the mechanics of the labor market.

Second, there are many hurdles to wage adjustment in the labor market. These hurdles sometimes force wages to remain above market-clearing levels, leading to job rationing.

Institutions such as unions or minimum wage laws are examples of such obstacles to wage adjustment. Internal labor markets are another one. Two well-documented characteristics of internal labor markets are relevant to explain why they may lead to job rationing. First, the internal pay structure does not respond to competitive forces in external labor market. For instance, Doeringer and Piore (1971) emphasize that “the internal labor market is governed by a set of rules and procedure [...] The jobs within the internal labor market are shielded from the direct influences of competitive forces in the external labor markets” and that “these rules are not consistent with pricing and distribution of labor which would prevail in a competitive market”. Therefore, when aggregate demand for labor falls, wages are constrained to remain above market clearing levels, rationing the number of jobs in the economy. Second, wages in internal labor markets tend to be high to elicit effort and dedication from employees (Bewley 1999, Jacoby 1984). The internal-labor-market organization is pervasive today, and any human-resource textbook explains how to design effective internal labor markets (for example, Billikopf 2003). One naturally wonders why firms would accept to pay above-market-clearing wages to workers. Jacoby (1984) documents how, in the twentieth century, the labor market in the U.S. has slowly evolved from impermanent and market-oriented to bureaucratic, rule-bound, and secure. His historical analysis explains that internal labor markets have been adopted by most firms because they were more equitable than the older “drive system”, so they improved workers’ morale and productivity, and eventually increased firm’s profits. Jacoby also suggests that some institutions have been instrumental to the adoption of internal labor markets: trade unions; government interventions during World War I, the Great Depression, and World War II; and the personnel management movement.

Introducing job rationing into a modern model of the labor market is not common, and economists often ask if we ever observe direct evidence of job rationing. Indeed we do. In bad times, people queue for jobs. In a famous scene from the film “Modern Times”, Charlie Chaplin opens the Daily News to see the headline that his old factory is rehiring. He runs off to the factory where he meets a crowd of hundreds of other workers seeking employment. He is the last one to sneak through the gate and be offered a job. The others are left waiting outside the gates of the factory. Long queues at job bureaus and at factory gates are indeed ubiquitous in the iconography of the Great Depression, as illustrated in Figures 1.1, 1.2, 1.3, and 1.4.

1.3 A Model with Matching Frictions and Job Rationing

The model of the labor market described in this dissertation builds on Mortensen and Pissarides’s (1994) search-and-matching 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 unemployment would disappear in the absence of matching fric-

tions.

To relax these assumptions, I develop a dynamic stochastic general equilibrium model in which large, monopolistic firms face a labor market with matching frictions, as in Blanchard and Galí (2008). All household members are in the labor force at all times, either working or searching for a job. Firms set prices and 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 many firms try to fill open positions while the pool of available unemployed workers is small.

In a frictional labor market there is no compelling theory of wage determination, which prompts the choice of a general wage schedule. Instead of deriving results for a particular wage-setting mechanism, I find conditions on the wage schedule for my results to hold. Furthermore, this generality allows me to nest as special cases various influential models of the search-and-matching literature, which provide valuable points of comparison.

Central to my analysis is job rationing. I assume that the marginal profit from hiring labor gross of recruiting expenses (the gross marginal profit) decreases with employment and could be exhausted before all workers are employed. Under this assumption, jobs are rationed when technology is low enough: even if recruiting costs were zero, workers could not all be profitably employed and some unemployment, which I call rationing unemployment, would remain. This is because profit-maximizing firms expand employment to the point where the gross marginal profit from hiring labor has fallen to the marginal cost of recruiting; in particular, firms do not hire past the point at which gross marginal profit is nil.

After an analysis of the general model, I specialize production function and wage schedule to propose a model in which the combination of diminishing marginal returns to labor and some wage rigidity yields job rationing. Intuitively, after a sufficiently large negative technology shocks: the marginal revenue product of labor falls; wages only partially adjust downward; such that wage may now be higher than the marginal revenue product of labor for the last workers in the labor force. Accordingly, firms cut employment to increase the marginal revenue product of labor as least until it equals the wage. In this model, jobs are rationed because not all workers could be employed even absent recruiting costs.

The assumptions of wage rigidity and diminishing marginal returns to labor are appealing because they are standard in the macroeconomic literature, and have received convincing empirical support. At business cycle frequency, some production inputs may be slow to adjust; thus, short-run production functions are likely to exhibit diminishing marginal returns to labor. There are also substantial ethnographic and empirical literatures documenting wage rigidity. Hence, job rationing arises naturally in a search-and-matching model of the labor market.

Finally, the model of the labor market put forward in the dissertation is amenable to evaluating in a single framework a number of labor market policies. I focus on three unemployment-reducing policies. The first one is direct employment, which hires unemployed workers in public-sector jobs, or offers contracts to private-sector firms to produce

goods consumed by the government. The second policy is placement services, which enhance unemployed workers' job-search efficiency to reduce matching frictions. The third policy is a wage subsidy, which reduces the cost of labor faced by private firms. Historically, governments have resorted to these policies on a large scale, and these three policies are the most commonly used by European states, along with training programs.

1.4 Contributions

This dissertation develops a tractable model that distinguishes between two components of unemployment: rationing unemployment, and frictional unemployment. By studying these components, I derive three results that improve our understanding of unemployment fluctuations: (i) I show that during a recession, rationing unemployment increases, driving the rise in total unemployment, while frictional unemployment decreases; (ii) I construct historical time series for frictional and rationing unemployment in a calibrated model of the labor market; (iii) I study the normative implications of these positive results to find that optimal unemployment-reducing policies should be adapted to the state of the labor market.

1.4.1 When do matching frictions matter? Not in bad times

I formally define the rationing component of unemployment as the part that would prevail if recruiting costs were zero, and the frictional component as additional unemployment due to positive recruiting costs. Rationing unemployment quantifies the amount of unemployment due to job rationing, whereas frictional unemployment quantifies the amount due to matching frictions.

This dissertation proposes a condition under which rationing unemployment is positive. Then, I prove theoretically that during a recession, rationing unemployment increases, driving the rise in total unemployment, while frictional unemployment decreases. This result suggests that job rationing trumps matching frictions to explain unemployment in recessions. These frictions however remain central to understand unemployment in expansions.

Intuitively, in recessions job rationing is more acute. Therefore rationing unemployment increases, raising total unemployment. This means that a firm posting a vacancy will receive more applications from the large pool of unemployed workers, and it will be able to fill its vacancy more rapidly, at a lower cost. So in recessions, because of matching frictions, the marginal cost of labor does not increase as much; monopolistic firms do not reduce production as much; there is not much additional unemployment. Consequently matching frictions contribute less to unemployment, and frictional unemployment is lower in recessions.

1.4.2 Historical time series for rationing unemployment and frictional unemployment

To quantify the fluctuations of frictional and rationing unemployment over the business cycle, I consider a special case of the general model in which the combination of diminishing marginal returns to labor and some wage rigidity leads to job rationing.

Calibrating the model and imposing technology shocks estimated in U.S. data produces moments for labor market variables that are close to their empirical counterparts. In particular, even a small amount of wage rigidity such as that estimated in microdata with earnings of newly hired workers (for example, Haefke et al. 2008), is sufficient to amplify realistic technology shocks as much as observed in the data. I also compare actual unemployment with the unemployment series simulated from actual technology. Model-generated unemployment matches actual unemployment closely. These results suggest that in spite of its simplicity, the model fits the data notably well, lending support to the quantitative analysis of unemployment and its components.

Exploiting the calibrated model, I decompose historical U.S. unemployment into historical time series for rationing unemployment and frictional unemployment. These series suggest that as long as total unemployment is below 5.2%, it can all be attributed to matching frictions. On average, total unemployment amounts to 5.8% of the labor force, frictional unemployment to 4.3%, and rationing unemployment to 1.5%. But in the second quarter of 2009, when total unemployment reached 9.2%, rationing unemployment increased to 7.6%, while frictional unemployment decreased to 1.6%. Next, I simulate moments for unemployment and its components. I find that rationing unemployment is more than twice as volatile as frictional unemployment.

Although concepts similar to those of frictional unemployment and rationing unemployment have long existed, this quantitative analysis has not previously been conducted.¹ As highlighted by Romer (2002), “We do not know if frictional unemployment is 1/4 or 3/4 of total unemployment”.

1.4.3 State-dependent labor market policies

This dissertation shows that when job rationing generates inefficiently high unemployment, labor market policies can improve welfare significantly. Specifically, I evaluate three labor market policies—direct employment, placement services, and a wage subsidy—over the business cycle. I assume that the government can commit to these policies. Policies are financed by an exogenous, stochastic stream of income, and by issuance of state-contingent debt.

¹Rationing unemployment is similar to *classical unemployment* if rationing results from real wage rigidities, as in Chapter 5. It is similar to *cyclical unemployment* if rationing results from demand shocks and price rigidity.

The fluctuations in rationing and frictional unemployment suggest that optimal unemployment-reducing policies should adapt to the changing state of the labor market. To formalize this intuition, I compute state-dependent fiscal multipliers—the increase in social welfare obtained by spending one dollar on a policy. I prove theoretically that placement services are more effective in good times than in bad times. The converse is true of direct employment. Intuitively, in bad times, frictional unemployment is low; placement services aim to further reduce this component and are therefore ineffective. The effectiveness of direct employment is a function of how much it crowds private employment out; in bad times, competition for workers is weak and crowding out is limited; thus, this policy is effective. In the calibrated model, wage subsidies are also more effective in bad times than in good times.

Then I characterize the optimal mix of policies implemented by a benevolent social planner. The optimal unemployment-reducing policy evolve over the business cycle: it puts more weight on policy instruments reducing matching frictions (placement services) in good times than in bad times; conversely, it puts more weight on policy instruments creating jobs directly (direct employment and a wage subsidy) in bad times than in good times. Intuitively, the optimal unemployment-reducing policy should adapt to the state of the labor market because of the cyclical fluctuations in the sources of unemployment.

1.5 Relation to the Literature

1.5.1 The search-and-matching framework

The decomposition of unemployment into rationing unemployment and frictional unemployment, as well as the characterization of the cyclical fluctuations in the components of unemployment, is new to the literature. In fact, existing models of unemployment only account for one single source of unemployment, and are not amenable to unemployment decomposition.

In particular, in existing search-and-matching models, there is no job rationing and all unemployment is frictional. In other words, in existing search-and-matching models, unemployment disappears when recruiting costs converge to zero. On the contrary, in my model with job rationing, some unemployment may remain even when recruiting costs converge to zero. The canonical search-and-matching model features atomistic firms in which the marginal product of labor remains above the value of unemployment for workers (for example, Mortensen and Pissarides 1994, Pissarides 2000). Once search costs are sunk, matches always generate a positive surplus, which is shared between firm and worker by Nash bargaining over wages. When recruiting costs converge to zero, the net profit from a match is positive for any level of employment. Consequently, firms enter the labor market until all the labor force is employed. The property that unemployment disappears when recruiting costs converge to zero also holds when rigid wages are introduced into the model (for example, Shimer 2004, Hall 2005a). This is because rigid wages are solely a way to divide the surplus

between firms and workers; thus, they always lie between the marginal product of labor, which is independent of employment, and the value of unemployment for workers. Lastly, this property holds in large-firm search-and-matching models with diminishing marginal returns to labor (for example, Cahuc and Wasmer 2001, Elsby and Michaels 2008). This is because these models use intrafirm bargaining mechanism. Therefore, without recruiting costs, the wage remains below the marginal product of labor for any level of employment.

The absence of job rationing in existing search-and-matching models is critical because without it, all unemployment is frictional. The absence of rationing unemployment has several important implications for the impact of labor market policies on unemployment: (i) policies improving matching are likely to always reduce unemployment; (ii) direct job creation by the government is likely to have no effect on unemployment; (iii) policies reducing the search effort of the unemployed are likely to always increase unemployment. This paper offers a more nuanced theory of unemployment over the business cycle in which job rationing is the most important source of unemployment in recessions and matching frictions are the most important source of unemployment in expansions. These results suggest that the effectiveness of labor market policies depends on the state of the labor market: (i) policies improving matching reduce unemployment in expansions but not in recessions; (ii) direct job creation by the government has no effect on unemployment in expansions but reduces unemployment in recessions; (iii) policies reducing the search effort of the unemployed, such as a generous unemployment insurance, increase unemployment in expansions but have no effect on unemployment in recessions. From a normative standpoint, these results imply that policymakers should adapt labor market policies to the state of the labor market.

1.5.2 The design of optimal fiscal policies

These policy results derived in the dissertation are related to two strands of literature. First, models based on search theories have been specifically designed to study particular labor market policies, but these policies have never been compared (for example, Mortensen and Pissarides 1999, Pissarides 2000, Cahuc and Zylberberg 2004). In addition, these studies do not emphasize the variations in the effectiveness of these policies at different points of the business cycle. Second, raising revenue to finance policies could be distortionary. I abstract from these distortions, and instead determine how to optimally spend tax revenue. Therefore, these results complement the large literature on optimal taxation, which determines the least costly way to finance an exogenous, stochastic amount of government spendings (for example, Barro 1979, Lucas and Stokey 1983, Chari et al. 1991, Chari et al. 1994, Aiyagari et al. 2002).

1.5.3 Macroeconomic models of unemployment

More generally, this paper contributes to the unemployment literature by integrating two major strands of research: the search-and-matching literature, which has become the stan-

dard theoretical framework for analyzing labor market fluctuations, and the job-rationing literature.

The Mortensen-Pissarides search-and-matching model has become the standard framework to analyze unemployment and labor market dynamics (Pissarides 1985, Mortensen and Pissarides 1994, Pissarides 2000). This model generates unemployment because workers cannot obtain jobs by bidding down wages to their reservation wage: in the presence of matching frictions, it takes time and effort to establish a contact with an employer. This model has been used widely in macroeconomics and related disciplines; it has been embedded into real business cycle models (Merz 1995, Andolfatto 1996), dynamic stochastic general equilibrium models with wage and price rigidities (Blanchard and Galí 2008, Gertler et al. 2008, Gertler and Trigari 2009), trade models (Helpman and Itskhoki 2007, Helpman et al. 2008), and has been studied to understand the impact of different policy interventions on unemployment (Mortensen and Pissarides 1999, Cahuc and Zylberberg 2004).

The job-rationing literature, on the other hand, dates at least as far back as Keynes' wage floor. Researchers in this literature drew on field studies by psychologists, sociologists, social psychologists, and anthropologists to motivate their models. This literature includes work on efficiency-wage models (Stiglitz 1976, Solow 1979, Akerlof and Yellen 1990), gift-exchange models (Akerlof 1982), insider-outsider models (Lindbeck and Snower 1988), and social-norm models (Solow 1980, Akerlof 1980).² These papers put forth different theories explaining why profit-maximizing firms may set wages above market-clearing levels. Generally, these theories postulate that higher wages increase effort and dedication to the firm, thus increasing productivity and profitability. These theories have received support from economists who studied wage-setting practices in the field (for example, Campbell and Kamlani 1997, Bewley 1999). As noted by Okun (1981): "Casual empiricism about the labor market suggests that the Keynesian wage floor nonetheless operates; the pay of car washers or stock clerks is seldom cut in a recession, even when it is well above any statutory minimum wage". In these models, unemployment is the equilibrium outcome from the shortage of job induced by excessively high wages.

In this dissertation, I show that unemployment is best described as a combination of frictional and rationing unemployment: the search-and-matching theory describes the labor market well in normal and good times; and job-rationing theory describes the labor market well in bad times; but only the integration of both theories adequately explains unemployment over the entire business cycle. This integration provides a better understanding of business-cycle fluctuations in the labor market, as well as novel and important policy

²My definition of job rationing rules out labor-turnover models (Stiglitz 1974), or shirking models (Shapiro and Stiglitz 1984). This choice is motivated by the observation that when a simple shirking model is used as a wage-setting mechanism in the canonical search-and-matching model, wages are extremely procyclical. In a calibrated model, wages fall by 40% when the unemployment rate climbs from 5% to 10%. Therefore, plausible shocks cannot generate fluctuations in unemployment and vacancy of the magnitude observed in the data.

recommendations.

1.6 Overview of the dissertation

The analysis begins with an elementary model of the labor market in Chapter 2, to provide intuition for the results of the dissertation. Chapter 3 describes the general framework on which my analysis rests: this is a dynamic stochastic general equilibrium model with frictional labor markets. In this model, I isolate general conditions for jobs to be rationed. In an environment with job rationing and frictions, I define rationing unemployment and frictional unemployment. Next, I theoretically study unemployment and its components to derive the results that: (i) job rationing, but not matching frictions, explain unemployment in recessions; and (ii) matching frictions solely explain unemployment in booms.

Chapter 4 describes several influential models from the search-and-matching literature as special cases of my general model. This chapter then proves that these existing models do not have job rationing: absent recruiting costs, unemployment would disappear.

Then, Chapter 5 specializes the general model to a simple production function and wage schedule. I isolate two assumptions on the primitive of the model that allow me to accommodate job rationing in an equilibrium framework: real wage rigidity and diminishing marginal returns to labor. I calibrate and evaluate this specific model. The empirical validity of the model lends support to theoretical result derived above, and allows me to pursue the quantitative work further. I decompose U.S. unemployment for the postwar period to construct historical time series for rationing unemployment and frictional unemployment. These time series illustrate how the theoretical results translate quantitatively. They suggest that the fluctuations in the composition of unemployment are quantitatively large.

Next, Chapter 6 asks how costly these unemployment fluctuations are. The cost of unemployment in the calibrated model is large, because job rationing generates inefficiently high unemployment. Hence, the implementation of labor market policies could improve welfare significantly. I evaluate three labor market policies—direct employment, placement services, and a wage subsidy—over the business cycle. Fluctuations in frictional and rationing unemployment suggest that optimal unemployment-reducing policies should adapt to the changing state of the labor market. In this chapter, I prove this intuition formally: policies tackling matching frictions are effective in expansions, but not in recessions; conversely, policies tackling job rationing are effective in recessions, but not in expansions.

Finally, Chapter 7 concludes and discusses directions for future research. Proofs are collected in the appendices placed at the end of each chapter, together with all tables and graphs.



Figure 1.1: Job rationing during the Great Depression. About 5,000 unemployed people queue to apply for one of 2,000 jobs outside City Hall in Cleveland, Ohio, in 1930 during the Great Depression. Photograph: Associated Press.



Figure 1.2: Queues at employment offices during the Great Depression. Lines stretched for blocks outside some employment offices in the 1930s. Source: <http://www.examiner.com/>.



Figure 1.3: Queues at job bureaus during the Great Depression. This photograph shows unemployed men vying for jobs at the American Legion Employment Bureau in Los Angeles during the Great Depression. Source: <http://www.english.illinois.edu/maps/depression/photoessay.htm>.



Figure 1.4: Queues at the Employment Service Office during the Great Depression. This photograph shows part of the daily lineup outside the State Employment Service Office in Memphis, Tennessee in June 1938. Photographer: Dorothea Lange. Source: <http://memory.loc.gov/ammem/fsahtml/fahome.html>

Chapter 2

Intuition from an Elementary Model of the Labor Market

2.1 Introduction

This chapter develops the simplest model of a labor market embodying two essential elements: frictions hindering matching of jobseekers with firms, and a possible shortage of jobs given the number of workers in the labor force.¹ Thus, in this model, both matching frictions and job rationing prevent full employment. This elementary model allows me to formally decompose unemployment into two components: rationing unemployment and frictional unemployment. Rationing unemployment is defined as the level of unemployment that prevails when matching frictions disappear. That is, rationing unemployment measures the shortage of jobs in the economy, irrespective of matching frictions. Frictional unemployment is defined as additional unemployment due to matching frictions.

The analysis of the model provides the key insights that when there are fewer jobs than workers and the number of jobs decreases further: (i) total unemployment and rationing unemployment increase, but frictional unemployment decreases; (ii) creating new jobs reduces unemployment more effectively; and (iii) improving matching reduces unemployment less effectively. The findings derived in this simple setting prefigure the main results of the dissertation.

2.2 Setup

This is a continuous-time environment. K jobs are matched with L workers. All workers, and all jobs, are identical; therefore, any worker can be matched with any job. At time t , there are N_t worker-job matches, V_t vacant jobs, and U_t unemployed workers. Jobs can

¹This model resembles that of Petrongolo and Pissarides (2001) and Blanchard and Diamond (1989).

either be vacant or filled with exactly one worker, and workers can either be unemployed or hired in exactly one job. Therefore, $N_t + U_t = L$ and $N_t + V_t = K$.

The stocks of vacancies and unemployed workers evolve as the result of a continuous process of match creation and destruction. The N_t existing worker-job matches are destroyed at rate s . When a match is destroyed, the worker becomes unemployed and the job becomes vacant.

There are frictions in the matching process; therefore, it takes time to fill the V_t open vacancies. Frictions originate both from the firm and worker side. On the one hand, I assume that it takes $\tau \in (0, +\infty)$ units of time—a *matching period*—for firms to collect applications, before they randomly pick one worker. On the other hand, I assume that each unemployed worker send applications at a finite rate $\omega \in (0, +\infty)$. Moreover, unemployed workers fail to coordinate with each other such that several unemployed workers may apply to the same vacancy during one matching period.

2.3 Matching Function

τ is the duration of a matching period. I assume that all firms coordinate matching, and advertise their vacant jobs at the same time. Let $\mathcal{T} = \{\tau, 2 \cdot \tau, 3 \cdot \tau, \dots\}$ be the set of times at which matching occurs, and firms post their new vacancies—the *matching times*. I study the evolution of unemployment and vacancies at these matching times.

During each matching period, each jobseeker sends one random application with probability $\omega \cdot \tau \leq 1$. If at least one application is received for a vacant job, the job is filled; otherwise, it remains vacant. If several workers apply to the same job, one of them gets the job; the others remain unemployed.

Let $t \in \mathcal{T}$ be a matching time. Since applications are random, conditional on applying, $1/V_t$ is the probability that a worker applies to a given vacancy. $\omega \cdot \tau$ is the probability that a worker sends an application during a matching period. Therefore, $(\omega \cdot \tau)/V_t$ is the probability that a worker applies to a given vacancy, and $[1 - (\omega \cdot \tau)/V_t]^{U_t}$ is the probability that a given vacancy does not receive any application during a matching period. The expected number of matches during a matching period starting with stocks U_t and V_t of unemployed workers and vacancies is therefore described by a matching function

$$h(U_t, V_t) = V_t \cdot \left[1 - \left(1 - \frac{\omega \cdot \tau}{V_t} \right)^{U_t} \right].$$

2.4 Steady-State Equilibrium

I study two endogenous variables in this economy: the unemployment rate $u_t \equiv U_t/L$, $t \in \mathcal{T}$, and the vacancy rate $v_t \equiv V_t/L$, $t \in \mathcal{T}$. The economy settles at a steady-state equilibrium

determined by the job destruction rate (s), workers' application rate (ω), the duration of the matching period (τ), and the number of jobs (K) and workers (L). Let u and v be the steady-state unemployment and vacancy rate.

The steady-state equilibrium is characterized by two equations, parameterized by the job-worker ratio in the economy $\kappa \equiv K/L$. First, an accounting identity imposes the condition that the number of employed workers equals the number of filled jobs:

$$u = (1 - \kappa) + v. \quad (2.1)$$

Second, stationarity of the stock of matches implies that during each matching period, the number of matches destroyed equals the number of new matches created:

$$s \cdot \tau \cdot (1 - u) = h(u, v). \quad (2.2)$$

I assume that the number of vacancies is large, and use the result that for a large V , $(1 - (\omega \cdot \tau) / V)^U$ is well approximated by $\exp(-\frac{\omega \cdot \tau \cdot U}{V})$. Thus, the matching function is given by

$$h(u, v) = v \cdot \left(1 - e^{-\frac{\omega \cdot \tau \cdot u}{v}}\right) = v \cdot \left(1 - e^{-\frac{\omega \cdot \tau}{\theta}}\right), \quad (2.3)$$

where

$$\theta \equiv \frac{v}{u} = \frac{V}{U} \quad (2.4)$$

is the ratio of vacancies to unemployment, or *labor market tightness*. The system (2.1)-(2.2), combined with the approximation of the matching function (2.3), yields comparative statics for unemployment and vacancies in equilibrium.

LEMMA 2.1. *In any steady-state equilibrium parameterized by a job-worker ratio $\kappa \in (0, +\infty)$:*

$$(i) \quad \nabla_{\kappa} u < 0;$$

$$(ii) \quad \nabla_{\kappa} v > 0;$$

$$(ii) \quad \nabla_{\kappa} \theta > 0.$$

$\nabla_{\kappa} u$ denotes the partial derivative of u with respect to κ . Lemma 2.1 shows that unemployment naturally increases when the number of jobs in the economy decreases relative to the size of the labor force, whereas the vacancy rate decreases at the same time.² Intuitively, when the job-worker ratio κ decreases, employment decreases. Therefore, a smaller number of new matches $h(u, v)$ are sufficient to balance job destruction to maintain the number of productive matches. Given that there are more unemployed workers looking for jobs, fewer

²In fact, one can show that $\nabla_{\kappa} v > \frac{s \cdot \tau}{1 + s \cdot \tau}$.

vacancies are required to obtain the same number of matches each period. Combining both effects, it is clear that there are fewer vacancies at a steady state in which the job-worker ratio is lower. The lemma implies that for a fixed labor force, the unemployment rate and the vacancy rate move in opposite directions as the number of jobs in the economy fluctuates: the points (u, v) describe a downward-sloping Beveridge curve.

2.5 The Frictionless Economy

For a given number of workers and jobs in the economy, the number of employed workers cannot be higher than the number of jobs. In this section, I show briefly that when firms collect and pick applications infinitely rapidly, and when unemployed workers increase their search effort infinitely to maintain a positive application probability each matching period, the economy converges towards this limiting case and all jobs are filled or all workers are employed.

LEMMA 2.2 (Frictionless economy). *Assume that $\tau \rightarrow 0$ and there exists $p \in (0, 1)$ such that $\omega \cdot \tau = p$. Then in the steady-state equilibrium parameterized by the job-worker ratio $\kappa \in (0, +\infty)$*

$$u \rightarrow \max \{1 - \kappa, 0\}.$$

Lemma 2.2 tells us that the economy can achieve the lowest-unemployment scenario when both firms and unemployed workers exert infinite search effort. I refer to this economy as the *frictionless economy*. In that case, the number of unemployed workers in the economy is $L - K$ if the labor force L is larger than the number of jobs K , or 0 otherwise. In other words, absent matching frictions, the number of matches is determined by the side of the labor market in shorter supply:

$$N = \min\{K, L\}.$$

2.6 Rationing Unemployment, and Frictional Unemployment

In this section, I define and characterize rationing unemployment and frictional unemployment in this elementary model.

DEFINITION 2.1 (Rationing unemployment and frictional unemployment). In any steady-state equilibrium parameterized by a job-worker ratio $\kappa \in [0, 1]$, I define

$$u^R = 1 - \kappa \tag{2.5}$$

$$u^F = u - u^R. \tag{2.6}$$

When $\kappa \in (1, +\infty)$, $u^R = 0$ and $u^F = u$. u^R is rationing unemployment, and u^F is frictional unemployment.

When the number of jobs K is smaller than the labor force L , employment equals $K < L$ in the frictionless economy and the economy is below full-employment. Rationing unemployment $u^R = \max\{1 - \kappa, 0\}$ represents this unemployment caused by the lack of jobs in the economy, independently of matching frictions. If there are more jobs than workers ($K \geq L$), then there is no unemployment in the frictionless economy. Hence, all unemployment is due to matching frictions, and rationing unemployment is nil. Frictional unemployment is simply defined as additional unemployment on top of rationing unemployment, caused by matching frictions.

LEMMA 2.3. *In any steady-state equilibrium parameterized by a job-worker ratio $\kappa \in [0, 1]$,*

$$u^F = v. \quad (2.7)$$

Lemma 2.3 shows that frictional unemployment coincides to vacancy rate. This result is natural. When there are less jobs than workers and no frictions, all jobs are filled at all time. Therefore, the number V of vacant jobs corresponds to the number of workers who are unemployed because of frictions; hence, additional unemployment rate caused by frictions is the vacancy rate.

I can now prove the key result of this chapter.

PROPOSITION 2.1. *In any steady-state equilibrium parameterized by a job-worker ratio $\kappa \in (0, 1)$:*

- (i) $\nabla_{\kappa} u^R < 0$;
- (ii) $\nabla_{\kappa} u^F > 0$.

Proposition 2.1 shows that when the number of jobs decreases relative to the size of the labor force, rationing unemployment increases, but frictional unemployment decreases. This result is intuitive. First, with a constant labor force, rationing unemployment mechanically increases when there are fewer jobs, because it is defined as the difference between the number of jobs and the number of workers. Second, matching frictions require some jobs to remain vacant in order to attract applications and generate new matches—these new matches balance job destructions in steady state. Therefore, frictions increase unemployment by reducing the number of productive jobs. When there are fewer jobs, there are more jobseekers; thus, each vacancy is more likely to receive at least one suitable application and generate a match; hence, fewer vacancies are needed in equilibrium and frictional unemployment decreases.

Figure 2.1– 2.2 illustrates these findings. Figure 2.1 shows that the probability that a vacancy generates a match decreases rapidly with the job-worker ratio $\kappa = K/L$. Figure 2.2

shows that frictional unemployment decreases and rationing unemployment increases when the job-worker ratio is less than 1 and decreases further. It is because vacancies are filled rapidly that frictional unemployment is low and matching frictions do not matter much in bad times.

2.7 Reducing Unemployment

In this section, I study the effectiveness of two methods to reduce unemployment in this elementary model: adding jobs, and improving matching. In particular, I analyze how their effectiveness varies with the state of the labor market.

PROPOSITION 2.2 (Adding jobs). *In any steady-state equilibrium parameterized by a job-worker ratio $\kappa \in (0, +\infty)$, the change in the unemployment level achieved by creating one more job is*

$$\nabla_{\kappa} u = -\frac{1 - (1 + \omega \cdot \tau / \theta) e^{-\omega \cdot \tau / \theta}}{1 + s \cdot \tau + (\omega \cdot \tau - 1 - \omega \cdot \tau / \theta) e^{-\omega \cdot \tau / \theta}} < 0.$$

This effect of job creation on unemployment decreases with the job-worker ratio κ :

$$\nabla_{\kappa}^2 u > 0.$$

This proposition suggests that job creation reduces unemployment, especially when the labor market is depressed. In particular, when the unemployment rate converges to one, one more job generates $\frac{1}{1+s \cdot \tau} \approx 1$ match. Intuitively, when workers outnumber jobs, a new job is likely to be filled rapidly (Figure 2.1), and is unlikely to be filled by an unemployed worker who would have found another job otherwise. Thus, when the unemployment rate is high, a new job reduces unemployment by nearly one count (Figure 2.3).

PROPOSITION 2.3 (Improving matching). *In any steady-state equilibrium parameterized by a job-worker ratio $\kappa \in (0, +\infty)$, the effect of improving matching on the unemployment level is*

$$\epsilon_u^{\omega} \equiv \frac{\omega}{u} \cdot \nabla_{\omega} u = -\frac{\omega \cdot \tau e^{-\omega \cdot \tau / \theta}}{1 + s \cdot \tau + (\omega \cdot \tau - 1 - \omega \cdot \tau / \theta) e^{-\omega \cdot \tau / \theta}} < 0.$$

This effect increases with the job-worker ratio κ :

$$\nabla_{\kappa} \epsilon_u^{\omega} < 0.$$

This proposition shows that an increase of the matching efficiency ω leads to a reduction in the number of unemployed. But the amplitude of the elasticity $|\epsilon_u^{\omega}|$ falls when job-worker

ratio κ (my measure of state of the labor market) decreases. In particular, when the job-worker ratio is close to zero, this elasticity tends to 0, and when the job-worker ratio converges to $+\infty$, the elasticity converges to $\frac{\omega}{s+\omega}$. This proposition highlights the limitations of policies improving matching in a depressed labor market. Intuitively, when workers outnumber jobs, each vacancy is almost certainly filled at the end of the matching period (Figure 2.1). Improving matching is tantamount to adding more jobseekers which barely increases the probability of a vacant job being filled, and barely increases the expected number of matches. Thus, when the unemployment rate is high, the elasticity of unemployment to matching efficiency is close to zero (Figure 2.4).

2.8 Concluding Remarks

The model provides the key insights that when there are fewer jobs than workers and the number of jobs decreases further: (i) total unemployment and rationing unemployment increase, but frictional unemployment decreases; (ii) creating new jobs reduces unemployment more effectively; and (iii) improving matching reduces unemployment less effectively.

The findings from this mechanical model could be applied to other problems in which a rationing constraint interacts with matching frictions. One such problem is urban parking, which involves a continuous process of cars parking and leaving parking spots. This chapter explains how in San Francisco, the number of cars and parking spots in the city, together with drivers' lack of information about the location of parking spots, determines the parking time in San Francisco. The main result is that on weekdays, when few cars drive into the city, the time spent to find a parking spot is mostly determined by matching frictions; but on weekends, when a large flow of cars drive into the city, the discrepancy between the number of parking spots and the number of cars looking for parking determines the parking time in the city.

The advantage of this model is to provide a microfounded matching function, and to derive results in a simple and intuitive setting. However, the matching function is too naive to be a good empirical approximation to matching in real labor markets, and it must be generalized. In addition, creation of jobs in the labor market and job rationing must be endogenized. The rest of the dissertation finds that the results derived in this elementary model hold in the more sophisticated, dynamic stochastic general equilibrium framework with a calibrated matching function and endogenous job creation.

Appendix 2.A Proofs

Proof of Lemma 2.1. Using the approximation of the matching function given by (2.3), I get the following partial derivatives:

$$\nabla_u h = \omega \cdot \tau \cdot e^{-\frac{\omega \cdot \tau}{\theta}} \quad (2.8)$$

$$\nabla_v h = 1 - \left(1 + \frac{\omega \cdot \tau}{\theta}\right) e^{-\frac{\omega \cdot \tau}{\theta}}. \quad (2.9)$$

Given that $g : x \mapsto (1+x)e^{-x}$ is decreasing on $[0, +\infty)$ and $g(0) = 1$, then for any $(u, v) \in (0, +\infty) \times (0, +\infty)$, $\nabla_u h > 0$ and $\nabla_v h > 0$. Equations (2.1) and (2.2) define u, v as implicit functions of κ . For any $\kappa > 0$, the system admits a unique solution. The Implicit Function Theorem applies, and $u : (0, +\infty) \rightarrow [0, 1]$ and $v : (0, +\infty) \rightarrow (0, +\infty)$ are both continuous and differentiable functions of κ . Differentiating (2.1) and (2.2) yields:

$$\nabla_\kappa u (-s \cdot \tau - \nabla_u h) = \nabla_v h \cdot \nabla_\kappa v \quad (2.10)$$

$$\nabla_\kappa u = -1 + \nabla_\kappa v. \quad (2.11)$$

From (2.10), I infer that for any $\kappa \in (0, +\infty)$, $\nabla_\kappa u \cdot \nabla_\kappa v < 0$. From (2.11), I infer that for any $\kappa \in (0, +\infty)$, $\nabla_\kappa u < \nabla_\kappa v$. This proves the lemma.

Proof of Lemma 2.2. If $\omega \cdot \tau$ is constant, $h(.,.)$ does not depend on τ . Equation (2.2) implies that $h(u, v) \rightarrow 0$ when $\tau \rightarrow 0$, which implies $u \rightarrow 0$ or $v \rightarrow 0$. Given that $u \geq 0$ and $v \geq 0$, (2.1) implies that:

- when $1 - \kappa > 0$: $v = 0$ and $u = 1 - \kappa$,
- when $1 - \kappa < 0$: $v = \kappa - 1$ and $u = 0$.

Proof of Lemma 2.3. Derives immediately from (2.6) and (2.1).

Proof of Proposition 2.1. The proposition follows from equations (2.5), (2.7), and Lemma 2.1.

Proof of Proposition 2.2. The equilibrium conditions (2.1) and (2.2) give

$$s \cdot \tau(1 - u) = h(u, u + \kappa - 1). \quad (2.12)$$

Total differentiating with respect to κ and using (2.8) and (2.9) gives:

$$\begin{aligned} \nabla_\kappa u &= -\frac{\nabla_v h}{s \cdot \tau + \nabla_v h + \nabla_u h} \\ &= -\frac{1 - (1 + \omega \cdot \tau / \theta) e^{-\omega \cdot \tau / \theta}}{1 + s \cdot \tau - (1 + \omega \cdot \tau / \theta - \omega \cdot \tau) e^{-\omega \cdot \tau / \theta}}. \end{aligned}$$

Compounding the functions $x \mapsto (1+x)e^{-x}$ (decreasing on $[0, +\infty)$) and $x \mapsto \frac{1-x}{1+s-x}$ (decreasing on $[0, 1]$) gives the results in the text.

Proof of Proposition 2.3. Total differentiating the equilibrium condition (2.12) with respect to ω gives:

$$\begin{aligned} \frac{\omega}{u} \nabla_{\omega} u &= - \frac{\frac{\omega}{u} \nabla_{\omega} h}{s + \nabla_h v + \nabla_h u} \\ &= - \frac{\omega \cdot \tau \cdot e^{-\omega \cdot \tau / \theta}}{1 + s \cdot \tau - (1 + \omega \cdot \tau / \theta - \omega \cdot \tau) e^{-\omega \cdot \tau / \theta}} \end{aligned}$$

Compounding the functions $x \mapsto (1+x)e^{-x}$ (decreasing on $[0, +\infty)$), $x \mapsto \frac{x}{1+s \cdot \tau + x}$ (increasing on $[0, +\infty)$) gives the results in the text.

Appendix 2.B Graphs

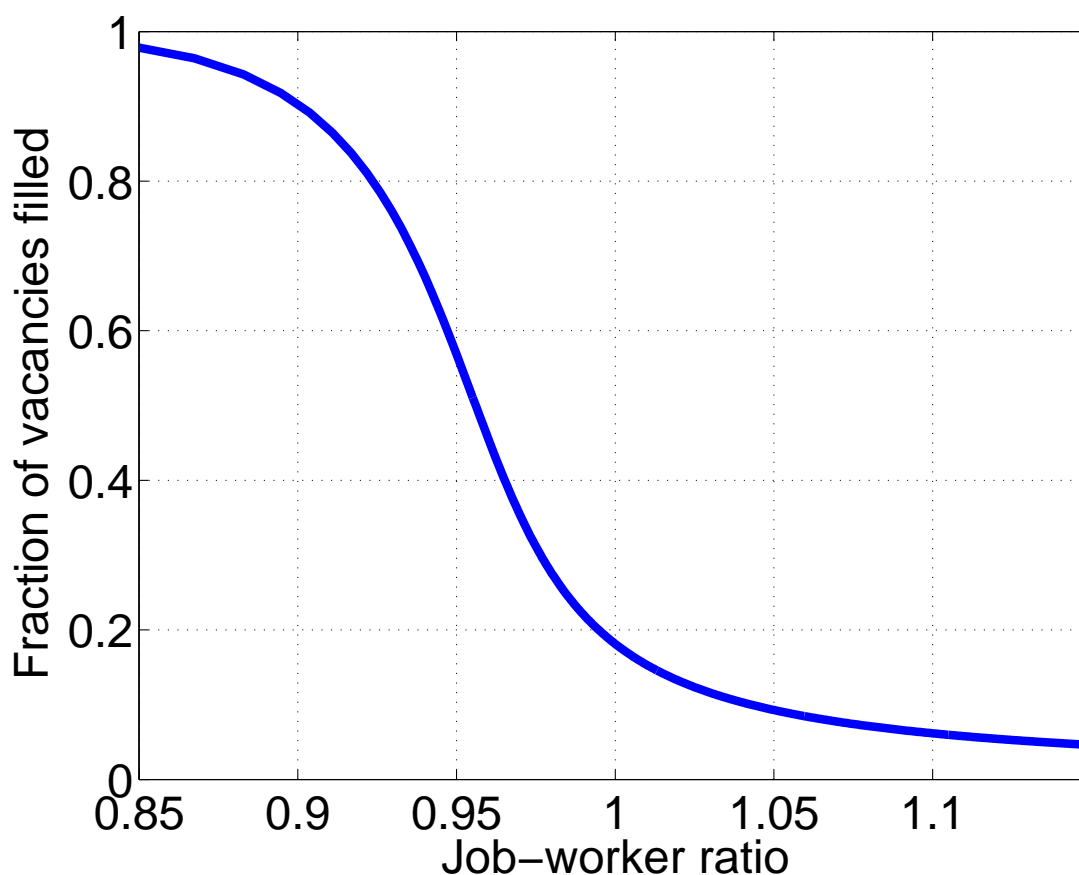


Figure 2.1: Job-filling probability in the elementary model. This graph shows the probability to fill a job in a given period, as a function of the ratio of the total number of jobs to the total number of workers. With a low ratio, jobs are scarce and equilibrium unemployment is high. With a high ratio, jobs are plenty and equilibrium unemployment is low. I choose $s = 0.095$, which is the weekly separation rate estimated in Section 5.4. I then pick $\omega = 0.20$, which yields an unemployment rate $u = 5.6\%$ for a vacancy-unemployment ratio $v/u = 0.45$, in line with U.S. data over the period 2001–2009. I first vary the job-worker ratio $\kappa = K/L$ in the range $[0.85, 1.15]$ to compute the corresponding equilibrium unemployment rate u and vacancy rate v from the system of equations (2.1)–(2.2). Then I compute the job-filling probability with (2.3).

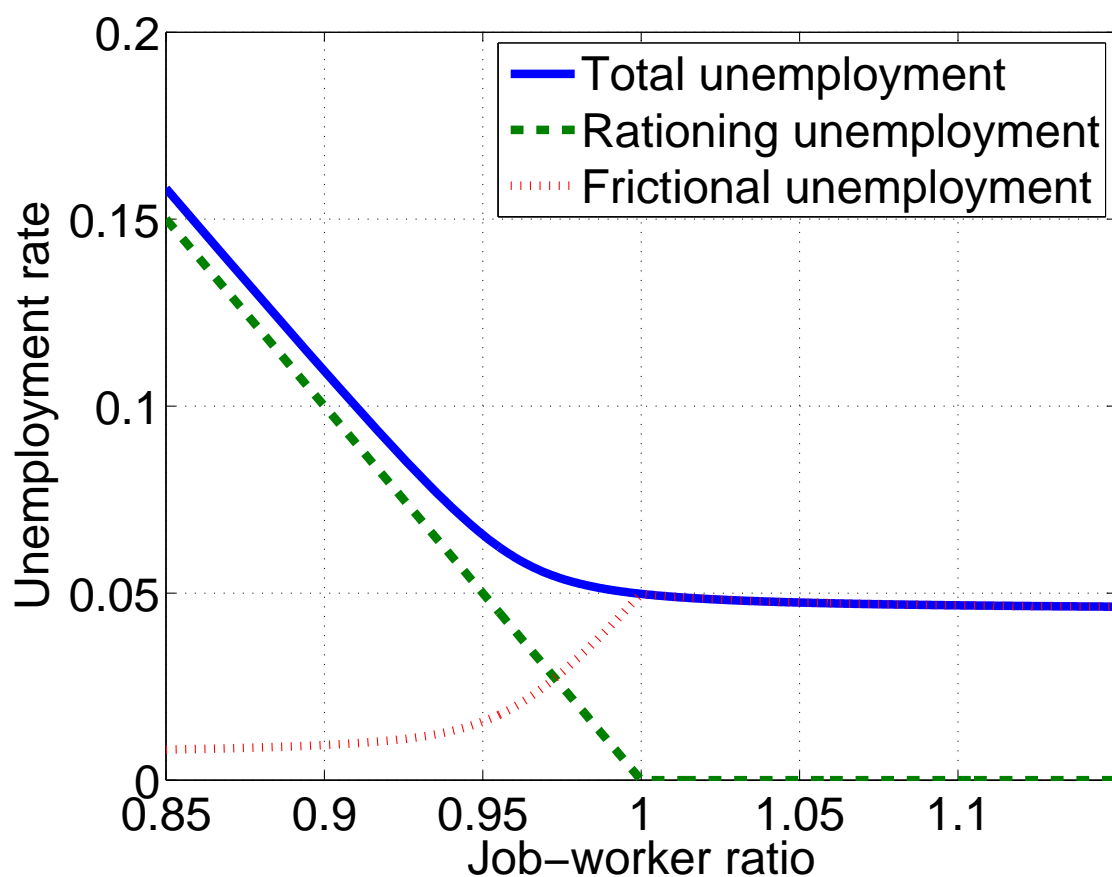


Figure 2.2: Beveridge curve in the elementary model. This graph shows equilibrium unemployment as a function of the ratio of the total number of jobs to the total number of workers. It also shows the decomposition of unemployment into frictional and rationing unemployment. The model is calibrated as in Figure 2.1. I first vary the job-worker ratio $\kappa = K/L$ in the range $[0.85, 1.15]$ to compute the corresponding equilibrium unemployment rate u and vacancy rate v from the system of equations (2.1)-(2.2). Then I compute the decomposition of unemployment with (2.5) and (2.7).

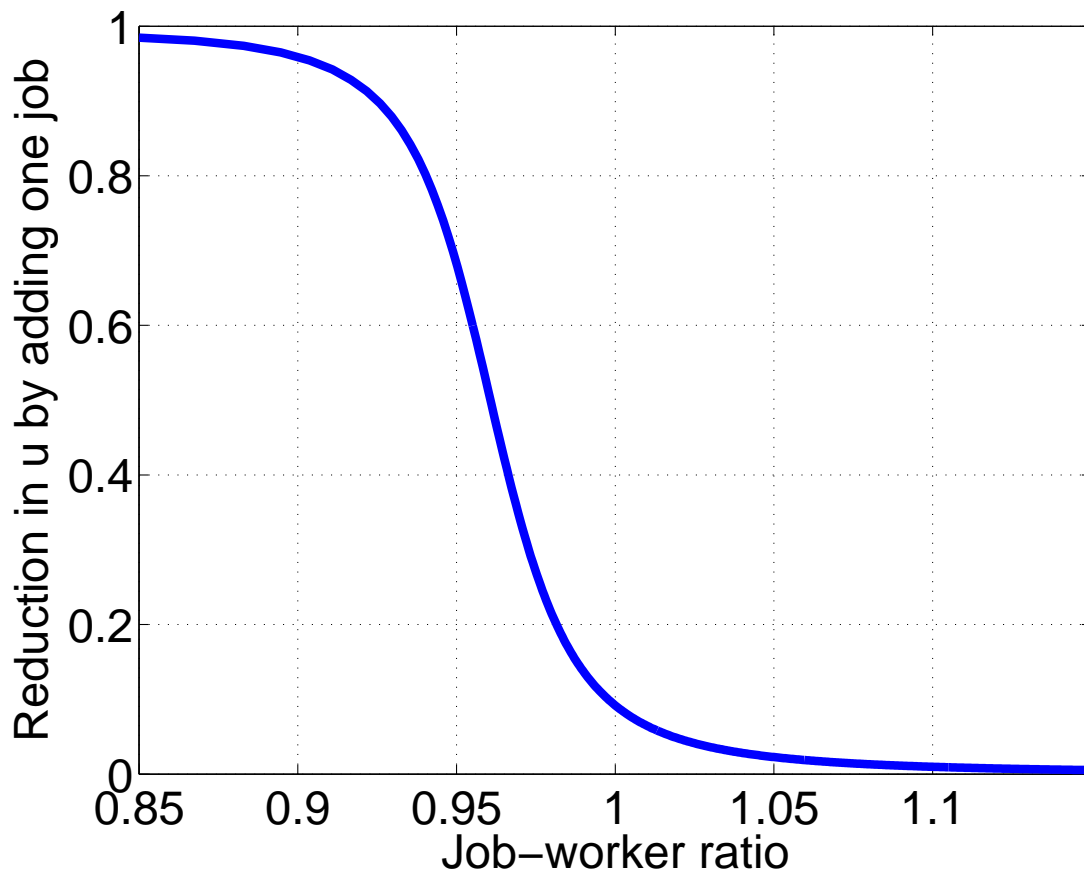


Figure 2.3: Effect of adding one job on unemployment in the elementary model. This graph shows the reduction in the number of unemployed workers that can be achieved by adding one more job in the economy, as a function of the state of the economy (measured by the ratio of the total number of jobs to the total number of workers). The model is calibrated as in Figure 2.1. I first vary the job-worker ratio $\kappa = K/L$ in the range $[0.85, 1.15]$ to compute the corresponding equilibrium unemployment rate u and vacancy rate v from the system of equations (2.1)-(2.2). Then I compute $|\nabla_K U| = |\nabla_\kappa u|$ with equation (2.2).

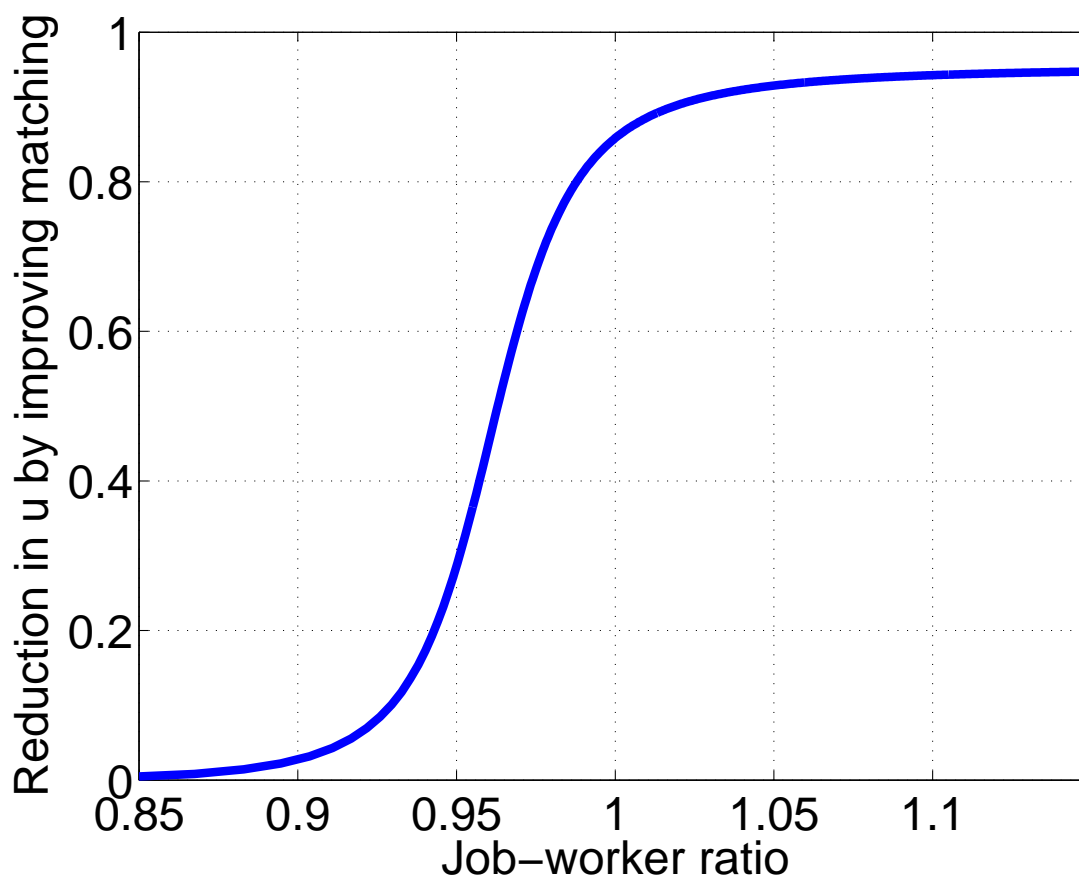


Figure 2.4: Effect of improving matching on unemployment in the elementary model. This graph shows the percentage reduction in unemployment that can be achieved by improving matching by 1%, as a function of the state of the economy (measured by the ratio of the total number of jobs to the total number of workers). The model is calibrated as in Figure 2.1. I first vary the job-worker ratio $\kappa = K/L$ in the range $[0.85, 1.15]$ to compute the corresponding equilibrium unemployment rate u and vacancy rate v from the system of equations (2.1)-(2.2). Then I compute $|\epsilon_u^\omega|$ with equation (2.3).

Chapter 3

A General Model of the Labor Market

3.1 Introduction

This chapter is the core of the dissertation. It presents a model that builds on the standard Neo-Keynesian model by adding matching frictions as in Blanchard and Galí (2008). The model is kept very simple to preserve tractability and portability. It is kept standard and relatively general to convince the reader that the results do not depend on specific assumptions, or on specific functional forms. As illustrated in Chapter 4, it nests influential search-and-matching models as special cases.

In this economy, all household members are in the labor force at all times, either working or searching for a job. Each period, the household spends all its income across differentiated goods; the household's behavior determines the demand faced by firms. Large, monopolistic firms set prices and hire workers from a frictional labor market, in response to exogenous job destruction and technology shocks. Firms' hiring decisions depend on current and expected recruiting costs, and on expected profits from a match. Recruiting is costly because of matching frictions, which are introduced in the labor market as in Pissarides (2000).¹. Recruiting is expensive especially in expansions when firms post many vacancies and the pool of unemployed workers is small, because it takes longer for firms to fill vacancies with unemployed workers. Conversely, recruiting is cheap in recessions when firms post few vacancies and the pool of unemployed workers is large, because vacancies can be filled in a short amount of time.

An important feature of the labor market in search-and-matching models is that matching frictions create a bilateral monopoly situation between workers and firms, because it is costly to locate new trade partners: firms must post a new vacancy, and workers must experience a spell of unemployment. The bilateral monopoly situation generates a surplus for each match that is created between a firm and a worker. In this setting, there is no compelling theory of

¹This model of the labor market is a simple version of Mortensen and Pissarides (1994)

wage determination, and a wide range of wages could be equilibrium outcomes (Hall 2005a). In fact, any wage-setting mechanism awarding a positive share of the surplus to the worker and the firm could be an equilibrium outcome because it is privately efficient. This property prompts me to work with a fairly general wage schedule. Instead of deriving results for a particular wage-setting mechanism, I assume that the wage belongs to a broad class of wage schedules and I find conditions on this schedule for my results to hold.

The main innovation of this model is to introduce the notion of job rationing in an equilibrium unemployment framework with matching frictions. To do so, I first define the gross marginal profit of a firm, which is the marginal profit from hiring labor gross of recruiting expenses. The gross marginal profit is independent of labor market conditions or recruiting costs. I assume that the gross marginal profit decreases with employment and could be exhausted before all workers are employed. Under this assumption, jobs are rationed when productivity is low enough: even if recruiting costs were zero, workers could not all be profitably employed and some unemployment, which I call rationing unemployment, would remain. This is because profit-maximizing firms expand employment to the point where the gross marginal profit from hiring labor has fallen to the marginal cost of recruiting; in particular, firms do not hire past the point at which gross marginal profit is nil. I then define frictional unemployment as additional unemployment due to the existence of positive recruiting costs.

This chapter aims to study theoretically the cyclical fluctuations of frictional and rationing unemployment in order to understand the importance of matching frictions and job rationing to explain unemployment over the business cycle. In recessions marginal profitability falls and job rationing is more acute. Therefore rationing unemployment increases, raising total unemployment. I find that at the same time, frictional unemployment decreases. Intuitively in recessions there are many unemployed workers and few vacancies, so each vacancy is filled rapidly and at low cost in spite of matching frictions. So in recessions, because of matching frictions, the marginal cost of labor does not increase as much; monopolistic firms do not reduce production as much; there is not much additional unemployment. Consequently matching frictions contribute less to unemployment, and frictional unemployment is lower in recessions.

3.2 Model

3.2.1 Source of fluctuations

This is a discrete-time model. Fluctuations are driven by technology, which follows a stochastic process $\{a_t\}_{t=0}^{+\infty}$. Firms and household make decisions whose time t components are functions of the history of realizations of technology $a^t = (a_0, a_1, \dots, a_t)$, and of the initial

employment level in the economy N_{-1} .²

This model takes the view that recessions are driven by shocks to aggregate activity, and not by reallocation shocks. This assumption is of course important for my analysis of the sources of cyclical fluctuations in unemployment, but it is now widely accepted. This view is supported by the findings from Abraham and Katz (1986), who found that aggregate shocks hit the entire economy in recessions.³ Blanchard and Diamond (1989) also compare the dynamic effects of aggregate activity, reallocation, and labor supply shocks to explain movements of unemployment and vacancies to find that aggregate activity shocks dominate, and that except at low frequencies, reallocation and labor force shocks contribute little to the fluctuations in the unemployment or the vacancy rate. This view is also supported by Hall (2005b), who finds that recessions are times when the labor markets of almost all industries slacken, and not times when workers move from industries with slack markets to others with tight markets. Hall concludes that a realistic model of the labor market needs to invoke a marketwide force that has powerful effects on the recruiting efforts of employers. As a consequence, in line with the search-matching literature, I assume stable matching function, and focus on aggregate shocks.

3.2.2 Households

The representative household is composed of a mass 1 of members. The household ranks consumption streams according to

$$\mathbb{E}_0 \left[\sum_{t=0}^{+\infty} \delta^t \cdot C_t \right], \quad (3.1)$$

where $\delta \in (0, 1)$ is the discount rate, and \mathbb{E}_0 denotes the mathematical expectation conditioned on time 0 information. C_t is the Dixit-Stiglitz composite consumption index defined by:

$$C_t = \left(\int_0^1 C_t(i)^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)},$$

where $\epsilon \in (1, +\infty)$, and $C_t(i)$ is the quantity of good $i \in [0, 1]$ consumed in period t . The price of good i is $P_t(i)$ and the aggregate price index is

$$P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di \right)^{1/(1-\epsilon)}.$$

²All firms are assumed to initially have the same size, so that N_{-1} determines initial employment in each firm.

³Abraham and Katz (1986) refuted earlier results by Lilien (1982), who suggested that recession may be primarily driven by reallocation shocks.

All household members participate in the labor market, and supply labor inelastically. The household has employed workers in all firms, and unemployed workers searching for a job. As in Merz (1995), the representative household construct gives rise to perfect risk sharing. Household members pool their income before choosing consumption. They face a budget constraint:

$$\int_0^1 P_t(i) \cdot C_t(i) di = P_t \cdot W_t \cdot N_t + P_t \cdot \pi_t. \quad (3.2)$$

W_t denotes the average real wage paid by firms, π_t denotes aggregate real profit made by firms, $P_t \cdot W_t \cdot N_t$ is total wage income, and $P_t \cdot \pi_t$ is aggregate nominal profit. I assume that the household owns all firms, and that firms redistribute all their profits to the household. The household is risk-neutral and consumes all income each period.⁴

DEFINITION 3.1 (Household problem). The household chooses a stochastic processes $\{C_t(i), C_t\}_{t=0}^{+\infty}$ to maximize (3.1) subject to the sequence of budget constraints (3.2), taking as given prices, wage, profits, and employment $\{P_t, P_t(i), W_t, \pi_t, N_t\}_{t=0}^{+\infty}$. The time t element of household's choice must be measurable with respect to (a^t, N_{-1}) .

Given aggregate consumption C_t , the household's optimal demand for good i is:

$$C_t(i) = C_t \cdot \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon}. \quad (3.3)$$

Then, the budget constraint can be rewritten to determines total consumption C_t :

$$C_t = W_t \cdot N_t + \pi_t.$$

The household problem is basic. There is no labor-supply decisions, neither in number of hours, nor in labor market participation. These assumptions are standard in the search-and-matching literature and are motivated by empirical work on the cyclical behavior of the

⁴ In their general equilibrium model, Blanchard and Galí (2008) introduce risk-averse agents that can save to smooth consumption because their focus is on the design of optimal monetary policy. In my case, savings are not relevant, and I simplify the exposition by abstracting from them. Introducing risk-aversion and allowing for savings would not change the theoretical predictions of the model. I explored the quantitative implications of this extension with a calibrated model in which (i) the household has log utility and (ii) can purchase state-contingent securities to smooth consumption. The dynamics of the model are scarcely modified. For instance, in response to a negative technology shocks, the impulse response functions (IRFs) of the (log-linearized) models with risk-neutrality and with risk-aversion are nearly identical. On impact, labor market tightness, recruiting, and output fall lower, but consumption remains higher with risk-aversion. The intuition is that firms recruit less to increase profits today, even if they incur lower profits in the future. The reason for this intertemporal substitution is that the future is more heavily discounted when risk-averse agents expect an increasing stream of consumption. However, the largest relative difference between IRFs in the risk-neutrality and risk-aversion case remain very low—below 1% for labor market tightness, or below 0.5% for consumption and output.

labor market, which suggests that hour per worker and labor force participation are quite acyclical. For instance, Shimer (2009) and Shimer (2010) provide evidence that most fluctuations in total hours worked at business-cycle frequency are accounted for by fluctuations in the employment-population ratio rather than by fluctuations in the number of hours per employee. We know since Blanchard and Diamond (1990) that a large fraction of flows in the labor market are from out-of-labor force to employment, and we may be worried that fluctuations in these flows matter at business cycle frequency. However, Shimer (2009) and Shimer (2010) suggest that movements in and out of the labor force only play a small role to explain cyclical fluctuations of unemployment. It seems that when employment falls below trend, most workers show up unemployed and do not drop out of labor force. Nonparticipation in the labor market seems to be relatively acyclic.

3.2.3 Labor Market

Workers can be hired by a continuum of firms indexed by $i \in [0, 1]$. 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 , a pool U_{t-1} of unemployed workers are looking for a job:

$$U_{t-1} = 1 - (1 - s) \cdot N_{t-1}. \quad (3.4)$$

Search frictions in the labor market require firms to spend resources to recruit new workers. V_t is the number of vacancies opened by firms at the beginning of period t , and $\theta_t \equiv V_t/U_{t-1}$ is the labor market tightness. The number of matches made in period t is given by a constant-returns matching function $h(U_{t-1}, V_t)$, which is differentiable and increasing in both arguments. An unemployed worker finds a job with probability

$$f(\theta_t) = \frac{1}{U_{t-1}} \cdot h(U_{t-1}, V_t) = h(1, \theta_t),$$

and a vacancy is filled with probability

$$q(\theta_t) = \frac{1}{V_t} \cdot h(U_{t-1}, V_t) = h\left(\frac{1}{\theta_t}, 1\right) = \frac{f(\theta_t)}{\theta_t}.$$

Labor market tightness θ_t summarizes labor market conditions. In a tight market, it is easy for jobseekers to find new 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.

To simplify the firm's problem, I assume no randomness at the firm level, so that a firm posting n vacancies gets $q(\theta_t) \cdot n$ workers. $c \in (0, +\infty)$ is the per-period cost of a vacancy (e.g., advertising cost), expressed in units of composite consumption. Therefore, a firm

spends

$$R(\theta_t, c) = \frac{c}{q(\theta_t)} \quad (3.5)$$

to recruit a worker immediately. When the labor market becomes tighter, firms must post more vacancies to attract new hires (e.g., advertise the same job in many more newspapers), and recruiting becomes more costly.

In this setting, 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 $H_t = \int_0^1 H_t(i) di$. The aggregate number of new hires H_t , labor market tightness θ_t , and unemployment U_{t-1} are related by the job-finding probability:

$$f(\theta_t) = \frac{H_t}{U_{t-1}}. \quad (3.6)$$

Upon hiring, $N_t(i) = (1 - s)N_{t-1}(i) + H_t(i)$ workers are employed in firm i . The aggregate number of employed workers is $N_t = \int_0^1 N_t(i) di$. Production occurs once firms have hired workers.

3.2.4 Wage schedule

Wages are set once employment has been determined. Hence, hiring costs are sunk at the time of wage setting. As argued by Hall (2005a), there is no compelling theory of wage determination in this context, and many wage schedules may be consistent with equilibrium. I assume that the wage schedule is additively separable in three components, each influenced by a different source of wage fluctuation:

$$W_t(i) = \mathbb{E}_t [W(N_t(i), \theta_t, \theta_{t+1}, a_t)] \equiv S(N_t(i), a_t) + X(\theta_t, c) + \mathbb{E}_t [Z(\theta_{t+1}, c)], \quad (3.7)$$

where $W_t(i)$ is the wage paid by firm i to all its workers at time t , and \mathbb{E}_t denotes the mathematical expectation conditioned on time t information. This formulation allows for the possibility that firms affect wages via their choice of employment, for instance as in Stole and Zwiebel's (1996a) intrafirm bargaining.⁵

This wage schedule has a natural interpretation. Since technology (a_t) and employment ($N_t(i)$) determine current marginal productivity in the firm, they are likely to affect wages paid to workers. Labor market tightness in the current period (θ_t) and in the next (θ_{t+1}) determine outside opportunities of firms and workers, and are likely to affect wages as well.⁶

⁵In Stole and Zwiebel's (1996a) intrafirm bargaining, employment impacts marginal productivity in the firm, which in turns impacts the surplus from the marginal match, and bargained wages.

⁶Expectations about next period's state of the labor market matter because workers will be on the labor

In fact, the term $S(N_t(i), a_t)$ captures the influence of technology and employment on wages; the term $X(\theta_t, c)$ captures the influence of current labor market conditions; and the term $\mathbb{E}_t[Z(\theta_{t+1}, c)]$ captures the influence of the labor market conditions expected next period.

This wage schedule is not completely general, but as shown in Chapter 4, it nests as special cases the schedules from a broad set of wage-setting mechanisms used in the literature: the generalized Nash bargaining (Mortensen and Pissarides 1994); Stole and Zwiebel's (1996a) intrafirm bargaining (Cahuc et al. 2008); and reduced-form rigid wages (Shimer 2004, Blanchard and Galí 2008).

I make the following assumptions on the wage schedule.

ASSUMPTION 3.1. $S : [0, +\infty) \times [0, +\infty) \rightarrow (-\infty, +\infty)$, $X : [0, +\infty) \times [0, +\infty) \rightarrow (-\infty, +\infty)$, and $Z : [0, +\infty) \times [0, +\infty) \rightarrow (-\infty, +\infty)$ are continuous and differentiable in all arguments.

ASSUMPTION 3.2. For all $\theta \in [0, +\infty)$, $X(\theta, 0) = 0$ and $Z(\theta, 0) = 0$. For all $c \in [0, +\infty)$, $X(0, c) = 0$ and $Z(0, c) = 0$.

ASSUMPTION 3.3. For all $(\theta, c) \in [0, +\infty) \times [0, +\infty)$, $\nabla_\theta(X + Z) \geq 0$.

Assumption 3.2 ensures that when recruiting costs or labor market tightness are nil, labor market conditions do not influence wages. Assumption 3.3 imposes that in a stationary environment, wages increase with labor market tightness. Intuitively, when the labor market is tighter, it is more costly for firms to recruit but easier for workers to find jobs; thus, labor market conditions are more favorable to workers, which will increase wages. Assumptions 3.1, 3.2, and 3.3 are satisfied for all the specific schedules studied in Chapter 4.

3.2.5 Firms

The firm's expected sum of discounted real profits is:

$$\mathbb{E}_0 \left[\sum_{t=0}^{+\infty} \delta^t \cdot \pi_t(i) \right], \quad (3.8)$$

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

$$\pi_t(i) = Y_t(i) \cdot \frac{P_t(i)}{P_t} - W_t(i) \cdot N_t(i) - R(\theta_t, c) \cdot H_t(i).$$

$Y_t(i)$ is the demand firm i faces, $\frac{P_t(i)}{P_t}$ is the relative price it sets, and $W_t(i)$ is the average real wage it pays. Aggregate real profit satisfies $\pi_t = \int_0^1 \pi_t(i) di$.

market next period if bargaining negotiations break down, if they quit, or if they are dismissed.

Firm i 's production function $F(N_t(i), a_t)$ is differentiable and increasing in both arguments. Firm i faces a production constraint:

$$Y_t(i) \leq F(N_t(i), a_t). \quad (3.9)$$

It also faces a constraint on the number of workers employed in period t :

$$N_t(i) \leq (1 - s) \cdot N_{t-1}(i) + H_t(i). \quad (3.10)$$

DEFINITION 3.2 (Firm problem). The firm chooses a stochastic processes $\{H_t(i), P_t(i)\}_{t=0}^{+\infty}$ to maximize (3.8) subject to the sequence of production constraints (3.9) and recruitment constraints (3.10), taking as given the wage schedule (3.7), as well as aggregate price, labor market tightness, and technology $\{P_t, \theta_t, a_t\}_{t=0}^{+\infty}$. The time t element of a firm's choice must be measurable with respect to (a^t, N_{-1}) .

In equilibrium, endogenous layoffs never occur. Therefore, firms recruit some workers each period, and the Lagrangian for the firm problem is simply:

$$\begin{aligned} \mathcal{L} = \mathbb{E}_0 \sum_{t=0}^{+\infty} \delta^t \left\{ Y_t \cdot \left(\frac{P_t(i)}{P_t} \right)^{1-\epsilon} - [S(N_t(i), a_t) + X(\theta_t, c) + Z(\theta_{t+1}, c)] \cdot N_t(i) \right. \\ \left. - R(\theta_t, c) \cdot [N_t(i) - (1 - s) \cdot N_{t-1}(i)] + \nu_t \cdot \left[F(N_t(i), a_t) - Y_t \cdot \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} \right] \right\}, \end{aligned}$$

where ν_t is the Lagrange multiplier associated with the production constraints and reflects the marginal profit from producing one more item. The first-order condition with respect to $P_t(i)$ yields

$$\frac{P_t(i)}{P_t} = M \cdot \nu_t, \quad (3.11)$$

where $M \equiv \frac{\epsilon}{\epsilon-1}$ is the markup charged by the monopoly. First-order condition (3.11) also implies that the monopolist sets its relative price as a markup over the marginal cost of producing one more item. The first-order condition with respect to $N_t(i)$ yields

$$\nu_t \cdot \nabla_N F(N_t(i), a_t) = W_t + R(\theta_t, c) + N_t(i) \cdot \nabla_N S(N_t(i), a_t) - \delta \cdot (1 - s) \cdot \mathbb{E}_t [R(\theta_{t+1}, c)]. \quad (3.12)$$

First-order condition (3.12) says that firm i hires labor until marginal profit from hiring equals marginal cost. The marginal profit is the product of the marginal profit from producing one more item (ν_t) and the marginal product of labor ($\nabla_N F(N_t(i), a_t)$). Marginal cost is the sum of the wage (W_t), the recruiting cost ($R(\theta_t, c)$), the change in the wage bill from increasing employment marginally ($N_t(i) \cdot \nabla_N S(N_t(i), a_t)$), minus the discounted cost

of recruiting a worker next period $(\delta \cdot (1 - s) \cdot \mathbb{E}_t [R(\theta_{t+1}, c)])$.

3.2.6 Resource constraint

All production in the economy is constrained to be either consumed or allocated to recruiting:

$$Y_t = \int_0^1 C_t(i) di + R(\theta_t, c) \cdot H_t, \quad (3.13)$$

where Y_t is total output in period t :

$$Y_t = \int_0^1 Y_t(i) di. \quad (3.14)$$

3.3 Equilibrium

This section defines and specifies an equilibrium for the model. It starts by characterizing the equilibrium condition that private efficiency of worker-firm matches be respected at all times. This condition implies that no inefficient worker-firm separations occur in equilibrium; that is, worker-firm matches generating a positive surplus are never destroyed.

3.3.1 No-inefficient-separation condition

In the model, existing employment relationships generate a positive surplus because there is a cost to matching a firm with a worker (Hall 2005a). A worker-firm match is privately efficient as long as it maintains a positive surplus for both parties: in this case there is no opportunity for mutual improvement. Any wage schedule that ensures the private efficiency of existing relationships at all times is consistent with equilibrium. In fact, equilibrium requires that neither workers nor firms endogenously break an existing match since any match generates some surplus.⁷ Workers do not have any endogenous incentive to quit; therefore, the sole restriction on the wage schedule is that it remains low enough to prevent endogenous layoffs. A firm's optimal hiring behavior is detailed in Lemma 3.1.

LEMMA 3.1. *Let the price $\hat{P}_t(i)$ be defined $\forall t \geq 0$ by*

$$Y_t \cdot \left(\frac{\hat{P}_t(i)}{P_t} \right)^{-\epsilon} = F((1 - s) \cdot N_{t-1}(i), a_t).$$

⁷Equivalently, the only separations observed in equilibrium are the exogenous destructions of a fraction s of all jobs each period.

Then, let the marginal profit $\hat{\nu}_t(i)$ be defined by

$$\hat{\nu}_t(i) = \frac{1}{M} \cdot \frac{\hat{P}_t(i)}{P_t}.$$

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.

$\hat{P}_t(i)$ is the highest price that firm i can charge without any layoffs. If it charged a higher price, its demand would fall, it would reduce production, and would eventually lay some workers off. Thus $\hat{\nu}_t(i)$ is the highest marginal profit that firm i can obtain with no layoffs. The firm's marginal cost function is discontinuous at the beginning-of-period employment level $(1-s) \cdot N_{t-1}(i)$ because hiring new workers is costly, whereas freezing hiring or laying workers off is costless. $\nu_t^L(i)$ is the limit of the marginal cost function from below. It is the highest marginal cost that the firm possibly faces if it lays some workers off, and the marginal cost it faces if it freezes hiring. $\nu_t^H(i) > \nu_t^L(i)$ is the limit of the marginal cost function from above. It is the lowest marginal cost that the firm possibly faces if it hires some workers. The optimal decision of a monopolist is characterized by the equality of marginal costs and marginal revenues.⁸ 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.

ASSUMPTION 3.4. Let $\{N_t\}_{t=0}^{+\infty}$ and $\{\theta_t\}_{t=0}^{+\infty}$ be stochastic processes for aggregate employment and labor market tightness. I assume that the wage schedule satisfies $\forall t \geq 0$:

$$\begin{aligned} \frac{M}{\nabla_N F((1-s) \cdot N_{t-1}, a_t)} \{ & (1-s) \cdot N_{t-1} \cdot \nabla_N S((1-s) \cdot N_{t-1}, a_t) + S((1-s) \cdot N_{t-1}, a_t) \\ & + \mathbb{E}_t [Z(\theta_{t+1}, c)] - \delta \cdot (1-s) \cdot \mathbb{E}_t [R(\theta_{t+1}, c)] \} \leq 1. \end{aligned} \quad (3.15)$$

Using Lemma 3.1 and the actual characterization of thresholds ν^H and ν^L , Proposition 3.1 offers a condition on the wage schedule such that private efficiency of worker-firm matches is respected at all times.

⁸To ensure uniqueness of the solution to the firm's optimization program, I assume that the marginal cost function increases with employment.

PROPOSITION 3.1 (No-inefficient-separation condition). *Let $\{N_t\}_{t=0}^{+\infty}$ be the stochastic process for aggregate employment in a symmetric equilibrium. Let $\{\theta_t\}_{t=0}^{+\infty}$ be the corresponding process for labor market tightness, defined from aggregate employment using (3.4) and (3.6). Then hiring freezes occur with probability zero. A necessary and sufficient condition for inefficient worker-firm separations not to occur is that the wage schedule satisfies Assumption 3.4.*

In a symmetric equilibrium, if no firm recruits, $\theta_t = 0$ and $R(0, c) = 0$. Thus, once the symmetric behavior of firms is aggregated, the marginal cost function is continuous in employment and there are no hiring freezes. Condition (3.15) ensures that the technology-dependent component of the wage $S((1-s) \cdot N_{t-1}, a_t)$ falls sufficiently relative to the decrease in marginal product of labor $\nabla_N F$ in response to an adverse technology shock. In Chapter 5, I propose a specific model with job rationing and derive a condition on the primitives of the model—production function, wage schedule, and stochastic process for technology—such that (3.15) holds.

3.3.2 Definition and characterization of the symmetric equilibrium

I normalize the aggregate price level P_t to remain constant over time.

DEFINITION 3.3 (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

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

that solve the household and firm problems, satisfy the law of motion for unemployment (3.4), the law of motion for labor market tightness (3.6), the wage schedule (3.7), the resource constraint (3.13), and respect the no-inefficient-separation condition (3.15).

A symmetric equilibrium satisfies the following conditions:

- Law of motion for employment:

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

- Law of motion for unemployment:

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

- Law of motion for labor market tightness:

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

- Resource constraint:

$$Y_t = C_t + R(\theta_t, c) \cdot H_t$$

- Production constraint:

$$Y_t = F(N_t, a_t)$$

- Wage rule:

$$W_t = S(N_t, a_t) + X(\theta_t, c) + \mathbb{E}_t [Z(\theta_{t+1}, c)]$$

- Firm's Euler equation:

$$\frac{\nabla_N F(N_t, a_t)}{M} = N_t \cdot \nabla_N S(N_t, a_t) + W_t + R(\theta_t, c) - (1 - s) \cdot \delta \cdot \mathbb{E}_t [R(\theta_{t+1}, c)] \quad (3.16)$$

- No-inefficient-separation condition:

$$\begin{aligned} \frac{M}{\nabla_N F((1 - s) \cdot N_{t-1}, a_t)} \{ & (1 - s) \cdot N_{t-1} \cdot \nabla_N S((1 - s) \cdot N_{t-1}, a_t) \\ & + S((1 - s) \cdot N_{t-1}, a_t) - (1 - s) \cdot \delta \cdot \mathbb{E}_t [R(\theta_{t+1}, c)] \} \leq 1 \end{aligned}$$

3.4 Some Definitions

In this section, I introduce job rationing to define rationing and frictional unemployment. Then, I study the properties of unemployment and its components.

3.4.1 Job rationing

DEFINITION 3.4 (Gross marginal profit). For all $(N_t, a_t) \in (0, 1] \times (0, +\infty)$, I define the *gross marginal profit* as

$$J(N_t, a_t) \equiv \frac{1}{M} \nabla_N F(N_t, a_t) - S(N_t, a_t) - N_t \cdot \nabla_N S(N_t, a_t). \quad (3.17)$$

$J(N_t, a_t)$ represents the marginal profit from an additional match gross of the marginal cost imposed by labor market frictions. This marginal cost is the sum of a recruiting cost $R(\theta_t, c)$, a cost $X(\theta_t, c) + \mathbb{E}_t [Z(\theta_{t+1}, c)]$ imposed indirectly through the wage schedule, minus the opportunity cost of hiring a worker next period $(1 - s)\delta \cdot \mathbb{E}_t [R(\theta_{t+1}, c)]$. In a symmetric equilibrium, a firm's Euler equation (3.16) can be rewritten as

$$J(N_t, a_t) = R(\theta_t, c) + X(\theta_t, c) + \mathbb{E}_t [Z(\theta_{t+1}, c)] - (1 - s)\delta \cdot \mathbb{E}_t [R(\theta_{t+1}, c)], \quad (3.18)$$

which imposes that the gross marginal profit equals the marginal cost associated with matching frictions in equilibrium.

ASSUMPTION 3.5. For all $a \in (0, +\infty)$, $\lim_{N \rightarrow 0} J(N, a) > 0$.

By Assumption 3.5, the gross marginal profit is always positive for the first worker hired by the firm. Combined with Assumption 3.2, steady-state production and employment are always positive. I now impose conditions on the gross marginal profit function $J : (0, 1] \times (0, +\infty) \rightarrow (-\infty, +\infty)$ that yield job rationing.

ASSUMPTION 3.6.

- (i) For all $(N, a) \in (0, 1] \times (0, +\infty)$, $\nabla_N J(N, a) < 0$.
- (ii) There exists $(N, a) \in (0, 1] \times (0, +\infty)$, $J(N, a) < 0$.

LEMMA 3.2. *Under Assumptions 3.5 and 3.6, there exists a non-empty, open interval $\mathcal{I} \subseteq [0, +\infty)$ such that for any $a \in \mathcal{I}$, the equation $J(N, a) = 0$ admits a unique solution $N^R(a) \in (0, 1)$. Let $\mathcal{A} = \cup \mathcal{I}$ be the union of all such open intervals. I shall refer to \mathcal{A} as the interval of rationing.*

Since the gross marginal profit $J(N, a)$ is decreasing in employment, worker-firm matches made when employment is above $N^R(a)$ yield a negative marginal profit. The profit from these matches is even more negative once the additional costs due to matching frictions are accounted for. In this sense, the number of jobs is rationed: no more than $N^R(a)$ jobs are created by profit-maximizing firms.

By assumption, when recruiting cost $c = 0$, the right-hand side of (3.18) is nil, because the marginal cost from matching frictions decreases to zero. Thus, without recruiting costs, equilibrium condition (3.18) becomes

$$J(N_t, a_t) = 0. \tag{3.19}$$

With technology in the interval of rationing, (3.19) admits a solution $N^R(a_t) < 1$, which can be interpreted as employment when there are no recruiting costs. The key implication of Assumption 3.6 is that the economy may remain below full-employment even when there are no recruiting costs. Adding recruiting costs leads firm to curtail employment further. Hence, both job rationing and search frictions cause unemployment.

3.4.2 Recessions

Productivity does not affect the recruiting cost function (R), or components of the wage schedule dependent on labor market conditions (X , Z). On the other hand, technology does influence the gross marginal profit J , because both the production function F and the

component S of the wage schedule depend on technology. The following assumption specifies the form of this influence, which drives fluctuations in the model.

ASSUMPTION 3.7. For all $(N, a) \in (0, 1] \times (0, +\infty)$, $\nabla_a J(N, a) > 0$.

ASSUMPTION 3.8. For all $(n, a) \in [0, N^R(a)) \times \mathcal{I}$, $\nabla_{n,a} J(N^R(a) - n, a) \leq 0$.

Assumption 3.7 implies that when technology falls, gross marginal profits fall. Assumption 3.8 implies that when technology falls, the slope of the gross marginal profit curve in the (employment, profit) plane does not decrease too much. These assumptions allow me to characterize the interval of rationing \mathcal{A} and fluctuations in N^R , as described in Lemma 3.3.

LEMMA 3.3. *Under Assumptions 3.5, 3.6, and 3.7:*

- (i) $\mathcal{A} = (0, +\infty)$ or there exists $a^R \in (0, +\infty)$, $\mathcal{A} = (0, a^R)$;
- (ii) $N^R : \mathcal{A} \rightarrow (0, 1)$ is continuous, differentiable, and for $a \in \mathcal{A}$: $\nabla_a N^R(a) > 0$.

Lemma 3.3 states that after a fall in technology, $N^R(a)$ falls and the constraint on employment becomes more stringent.⁹ Therefore, the shortage of jobs becomes more pronounced when the economy slides into a recession.

3.4.3 Rationing unemployment, and frictional unemployment

Assumption 3.6 introduces job rationing, which allows me to decompose equilibrium unemployment into rationing and frictional components.

DEFINITION 3.5 (Rationing and frictional unemployment). Let $\{a_t\}$ be the stochastic process for technology, and $\{U_t\}$ be the stochastic process for equilibrium unemployment. Under Assumption 3.6, I can construct two stochastic processes $\{U_t^R, U_t^F\}$. If $a_t \in \mathcal{A}$, their time t elements are defined by:

$$U_t^R \equiv 1 - N^R(a_t) \tag{3.20}$$

$$U_t^F \equiv U_t - U_t^C. \tag{3.21}$$

If $a_t \notin \mathcal{A}$, $U_t^R \equiv 0$ and $U_t^F \equiv U_t$. U_t^C is *rationing unemployment* at time t , and U_t^F is *frictional unemployment* at time t .

When technology a_t is in the interval of rationing \mathcal{A} , employment is bounded above by $N^R(a_t)$. Even if search costs are zero, employment equals $N^R(a_t) < 1$ and the economy is

⁹Assumption 3.8 is satisfied by a large class of functions, because a sufficient condition for it to hold is $\nabla_N^2 J(N, a) \geq 0$ and $\nabla_{N,a} J(N, a) \geq 0$.

below full-employment. Rationing unemployment U_t^R represents unemployment caused by job rationing; it reflects the lack of jobs in the economy, independently of matching frictions.

U_t^F can be expressed as a function of employment N_t and $N^R(a_t)$:

$$U_t^F = s \cdot N_t + [N^R(a_t) - N_t]. \quad (3.22)$$

The first term in (3.22) is unemployment due to job destruction during period t . It reflects the inflow of separated workers into unemployment at the end of period t , following end-of-period job destructions.¹⁰ The second term in (3.22) is additional unemployment caused by matching frictions. In fact, $N^R(a_t)$ would be the prevailing employment if there were no matching frictions. Once recruiting costs are taken into account, the marginal cost of labor increases and monopolistic firms reduce employment to $N_t < N^R(a_t)$. The difference between these two employment levels is additional unemployment caused by matching frictions.

3.5 Comparative Statics

This section derives results in an environment with no aggregate shocks: $a_t = a \forall t \geq 0$. I focus on the steady state of the economy. The equilibrium on the labor market can be described by three endogenous variables: unemployment U , employment N , and labor market tightness θ . They are determined by three equations: the definition of unemployment (3.4); the Beveridge curve (3.25); and a firm's Euler equation in steady state:

$$J(N, a) = X(\theta, c) + Z(\theta, c) + [1 - (1 - s) \cdot \delta] \cdot R(\theta, c), \quad (3.23)$$

which is the key equation of the system. The left-hand side of this equation is gross marginal profit from hiring labor, which is strictly decreasing in employment. The right-hand side is marginal cost caused by matching frictions: recruiting costs $R(\theta, c)$; plus the component of the wage depending on the state of the labor market $[X(\theta, c) + Z(\theta, c)]$; minus the opportunity cost of recruiting $(1 - s) \cdot \delta \cdot R(\theta, c)$. The right-hand side is strictly increasing in labor market tightness θ , and therefore strictly increasing in employment, which ensures uniqueness of the equilibrium.

PROPOSITION 3.2 (Comparative statics). *In an economy without aggregate shocks such that $a_t = a \in \mathcal{A} \forall t \geq 0$:*

$$(i) \quad \nabla_a U < 0;$$

$$(ii) \quad \nabla_a U^R < 0;$$

¹⁰This component would vanish in a continuous-time model and it is not central to understanding the unemployment dynamics studied in the next sections.

(iii) $\nabla_a U^F > 0$.

Proposition 3.2 implies that around any steady-state at which jobs are rationed, we have the following comparative-static results: when technology a decreases, total unemployment increases, rationing unemployment increases, but frictional unemployment decreases.

This results can be illustrated with a simple diagram. Expressing both labor market tightness θ and employment N as functions of unemployment U in (3.23), I can represent the steady-state equilibrium condition on a plane with unemployment on the x-axis and marginal profit on the y-axis. This simple diagram is shown in Figure 3.2. The upward-sloping, solid line is gross marginal profit $J(N, a)$. The downward-sloping, dotted line is the marginal cost imposed by matching frictions $X(\theta, c) + Z(\theta, c) + [1 - (1 - s) \cdot \delta] \cdot R(\theta, c)$. 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 when $c \rightarrow 0$, the marginal cost imposed by matching frictions $X(\theta, c) + Z(\theta, c) + [1 - (1 - s) \cdot \delta] \cdot R(\theta, c)$ falls to 0. Total unemployment is obtained at the intersection of the gross marginal profit and marginal cost curves, and frictional unemployment is the difference between total and rationing unemployment.

When technology decreases, the upward-sloping, gross marginal profit curve shifts to the right (diagram on the right in Figure 3.2). At the current employment level, gross marginal profit falls below the marginal cost of matching frictions. Thus, firms reduce hiring to increase gross marginal profit. At the aggregate level, lower recruiting efforts by firms reduce labor market tightness, which reduces the marginal cost of matching frictions. This corresponds to a movement along the downward-sloping marginal cost curve. The adjustment continues until gross marginal profit equals search-friction-related marginal cost. Then the economy reaches a new equilibrium, with high unemployment and lower labor market tightness.

Since the gross marginal profit curve shifts to the right, the constraint imposed by job rationing on employment is tighter, and rationing unemployment is higher. Since there are fewer jobs, the labor market is slacker and the marginal cost of matching frictions is lower. In particular, recruiting is less expensive in a slack labor market: many jobseekers apply to few vacancies, and each vacancy can be filled rapidly, at low cost. Hence, a smaller reduction in employment, from the level prevailing when the recruiting cost c is zero, suffices to bring the economy to equilibrium. Consequently frictions contribute little to unemployment, and frictional unemployment falls. Proposition 3.2 is extended in Proposition 3.3 to a dynamic setting.

3.6 Fluctuations of Unemployment and its Components Over the Business Cycle

This section extends the comparative-static results from Section 3.5 to a dynamic setting, which requires additional assumptions. To analytically characterize the behavior of unemployment and its components in an environment with aggregate shocks, I make the following approximation.

ASSUMPTION 3.9 (Stochastic equilibrium). Flows into employment and flows out of employment are equal:

$$f(\theta_t) \cdot U_{t-1} = s \cdot N_t. \quad (3.24)$$

This approximation is motivated by the observation that rates of job destruction and job creation 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 stochastic equilibrium of unemployment is a good approximation to the dynamic path of unemployment. Empirically, Hall (2005b) shows that actual unemployment scarcely deviates from its stochastic-equilibrium level in U.S. data over the 1948–2001 period; Rotemberg (2008) conducts a similar analysis to show that the stochastic equilibrium for unemployment tracks actual unemployment closely.¹¹ Finally, Chapter 5 numerically studies a model in which unemployment is not constrained to remain at its stochastic-equilibrium level, to confirm the robustness of the theoretical findings.

Assumption 3.9 allows an important simplification by linking unemployment U_t to labor market tightness θ_t through a Beveridge Curve

$$U_t = \frac{s}{s + (1 - s) \cdot f(\theta_t)}, \quad (3.25)$$

which can be depicted as a downward-sloping curve in the vacancy-unemployment plane (see Figure 3.1). If technology follows a first-order Markov process, then in equilibrium at each date $t \geq 0$, unemployment U_t , employment N_t , and labor market tightness θ_t solely depend on the realization of technology a_t (and not on the history of shocks a^t). These equilibrium values are determined by a system of three equations: (3.4), (3.18), and (3.25). In particular, I can define $U : (0, +\infty) \rightarrow [0, 1]$ such that $U(a)$ is the level of unemployment in equilibrium when the realization of technology is a . With definition 3.5 I can define two other functions, $U^R : (0, +\infty) \rightarrow [0, 1]$ and $U^F : (0, +\infty) \rightarrow [0, 1]$, such that $U^R(a)$ and $U^F(a)$ are the levels of rationing and frictional unemployment in equilibrium when the realization of technology is a . Proposition 3.3 states the fundamental result of this paper, which describes how unemployment and its components fluctuate with technology.

¹¹Equation (3.24) does not hold exactly all the time since unemployment varies. But flows into and out of employment are close enough most of the time to legitimately abstract from the adjustment dynamics of unemployment, and work under Assumption 3.9.

PROPOSITION 3.3 (Decomposition of unemployment). *Consider an economy with job rationing (Assumption 3.6), in which the derivatives of gross marginal profit satisfy some regularity conditions (Assumption 3.7 and 3.8). Assume that flows in and out of unemployment are equal (Assumption 3.9). Assume further that the stochastic process for technology $\{a_t\}$ follows a stationary, sufficiently autocorrelated AR(1) process (Assumption 3.11); that $\theta(\cdot)$ is sufficiently linear (Assumption 3.10); and that the variance of the technology process is small enough (Assumption 3.12). Then $\forall a \in \mathcal{A}$:*

- (i) $\nabla_a U < 0$;
- (ii) $\nabla_a U^R < 0$;
- (iii) $\nabla_a U^F > 0$.

This proposition shows that when jobs are rationed, total and rationing unemployment decrease with technology, whereas frictional unemployment increases. That is, when the economy enters a recessions, rationing unemployment increases, driving the rise in total unemployment; at the same time, frictional unemployment falls.

Empirically, it is reasonable to assume that technology follows a stationary, AR(1) process: $a_{t+1} = \rho a_t + z_{t+1}$ with a an autocorrelation coefficient ρ close to 1: in Section 5.4.1, I construct a quarterly technology series using data from the Bureau of Labor Statistics (BLS) to find that (log) technology is quite autocorrelated; I also repeat the analysis with the quarterly utilization-adjusted TFP series from Fernald (2009) to find that (log) TFP is highly autocorrelated; and Basu et al. (2006) find that yearly purified total factor productivity (TFP) is nearly a random walk. The AR(1) assumption and the assumptions following it in the text of Proposition 3.3 imply that firms avoid substituting too much recruiting intertemporally, which ensures that unemployment decreases with technology.¹² Appendix 3.B proves a similar result in a two-state economy under more general conditions on the stochastic process followed by technology.

3.7 Concluding Remarks

This chapter presents a dynamic stochastic general equilibrium model with frictional labor markets. In this model, I isolate general conditions on the production function and wage

¹²Assume that a state is characterized by low technology and a high probability of transitioning to a high-technology state, and another state is characterized by medium technology but lower probability of transitioning to a high-technology state. Recruiting could be higher and unemployment lower in the low-technology state than in the medium-technology state. In the former low-technology state, the opportunity cost of recruiting is low because recruiting is expected to be expensive next period. In the latter medium-technology state, the opportunity cost of recruiting is low because recruiting is expected to be cheap next period. If fluctuations in opportunity cost supersede those in marginal product of labor, unemployment may not be decreasing in technology.

schedule for jobs to be rationed; that is, some unemployment would remain in equilibrium even when recruiting costs vanish. In an environment with job rationing and frictions, I show that (i) job rationing, but not matching frictions, explain unemployment in recessions; and (ii) matching frictions solely explain unemployment in booms. I prove this result by studying theoretically the cyclical fluctuations in rationing unemployment, which represent the shortage of job in the economy irrespective of matching frictions, and frictional unemployment, which amounts to additional unemployment due to matching frictions.

These results prompt a set of questions. First, do existing models in the search-and-matching literature satisfy the conditions highlighted here for job rationing? Chapter 4 shows that they do not.

Next, which specification of the production function and wage schedule would lead to job rationing? And how large are the cyclical fluctuations of unemployment components in this specific model? Chapter 5 shows that job rationing naturally arises from a combination of real wage rigidity and decreasing marginal returns to labor. It also calibrates the specific model of job rationing, analyzes rationing and frictional unemployment quantitatively, to show that the fluctuations in the composition of unemployment are quantitatively large.

Another question is that of the optimality of unemployment in a model with matching frictions and job rationing. Chapter 6 computes the second-best allocation in this model to show that unemployment is actually very costly in a calibrated model. Accordingly, there is scope for policy intervention. What are the normative implications of positive results of this chapter? In Chapter 6, I introduce a set of labor market policies to combat labor market inefficiencies, and study the optimal design of unemployment-reducing policies in a dynamic setting.

Appendix 3.A Proofs

Proof of Lemma 3.1. I first define the Lagrangian for firm i 's problem, taking into account possibilities of layoffs:

$$\begin{aligned} \mathcal{L} = & \mathbb{E}_0 \sum_{t \geq 0} \delta^t \left\{ Y_t \left(\frac{P_t(i)}{P_t} \right)^{1-\epsilon} - N_t(i) \cdot [S(N_t(i), a_t) + X(\theta_t, c) + Z(\theta_{t+1}, c)] \right. \\ & \left. - \mathbf{1} \{ N_t(i) > (1-s)N_{t-1}(i) \} R(\theta_t, c) \cdot H_t(i) + \nu_t \left[F(N_t(i), a_t) - Y_t \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon} \right] \right\}. \end{aligned}$$

The firm faces a production constraint. Let $\hat{P}_t(i)$ be such that:

$$Y_t \left(\frac{\hat{P}_t(i)}{P_t} \right)^{-\epsilon} = F((1-s)N_{t-1}(i), a_t).$$

The maximum marginal profit that the firm can extract without laying workers off is

$$\hat{\nu}_t(i) = \frac{1}{M} \cdot \frac{\hat{P}_t(i)}{P_t}.$$

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

$$\begin{aligned} \nu_t^L(i) &= \frac{(1-s)N_{t-1}(i)\nabla_N S((1-s)N_{t-1}(i), a_t) + W_t - \delta \mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1}]}{\nabla_N F((1-s)N_{t-1}(i), a_t)} \\ \nu_t^H(i) &= \frac{(1-s)N_{t-1}(i)\nabla_N S((1-s)N_{t-1}(i), a_t) + W_t + R(\theta_t, c) - \delta \mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1}]}{\nabla_N F((1-s)N_{t-1}(i), a_t)}, \end{aligned}$$

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

$$\begin{aligned} \mathcal{L}_{t+1} &= \sum_{\tau \geq t+1} \delta^{\tau-(t+1)} \left\{ Y_\tau \left(\frac{P_\tau(i)}{P_\tau} \right)^{1-\epsilon} - N_\tau(i) \cdot [S(N_\tau(i), a_\tau) + X(\theta_\tau, c) + Z(\theta_{\tau+1}, c)] \right. \\ &\quad \left. - \mathbf{1}\{N_\tau(i) > (1-s)N_{\tau-1}(i)\} R(\theta_\tau, c) \cdot H_\tau(i) + \nu_\tau \left[F(N_\tau(i), a_\tau) - Y_\tau \left(\frac{P_\tau(i)}{P_\tau} \right)^{-\epsilon} \right] \right\}. \end{aligned}$$

Computing $\nu_t^L(i)$ and $\nu_t^H(i)$ requires computing $\mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1}]$. Let \mathcal{F} be the σ -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:

$$\mathcal{F} = \mathcal{F}^+ \cup \mathcal{F}^- \cup_{h=1}^{+\infty} \mathcal{F}^h. \quad (3.26)$$

\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:

$$\mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1}] = p^+ \times \mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1} | \mathcal{F}^+] + p^- \times \mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1} | \mathcal{F}^-] + \sum_{h=1}^{+\infty} p^h \times \mathbb{E}_t[\nabla_{N_t} \mathcal{L}_{t+1} | \mathcal{F}^h].$$

It is easy to show that:

$$\begin{aligned}
 \mathbb{E}_t [\nabla_{N_t} \mathcal{L}_{t+1} | \mathcal{F}^+] &= (1-s) \mathbb{E}_t [R(\theta_{t+1}, c) | \mathcal{F}^+] \\
 \mathbb{E}_t [\nabla_{N_t} \mathcal{L}_{t+1} | \mathcal{F}^-] &= 0 \\
 \mathbb{E}_t [\nabla_{N_t} \mathcal{L}_{t+1} | \mathcal{F}^h] &= \mathbb{E}_t \left[\sum_{j=t+1}^{t+h} \delta^{j-(t+1)} (1-s)^{j-t} \left\{ \frac{\nabla_N F((1-s)^{j+1-t} N_{t-1}(i), a_j)}{M} \right. \right. \\
 &\quad \left. \left. \times \left(\frac{F((1-s)^{j+1-t} N_{t-1}(i), a_j)}{Y_j} \right)^{-1/\epsilon} - \nabla_N S((1-s)^{j+1-t} N_{t-1}(i), a_j) - W_j \right\} | \mathcal{F}^h \right].
 \end{aligned}$$

Therefore, $\nu_t^L(i)$ and $\nu_t^H(i)$ are well defined, and depend on future realizations of $\{\theta_\tau, \tau \geq t+1\}$, 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 $\hat{\nu}_t(i)$.

Proof of Proposition 3.1. In symmetric environment, if a firm freezes hiring, all firms do so, $\theta_t = 0$, $R(\theta_t, c) = 0$, and for all i , $\nu_t^L(i) = \nu_t^H(i)$. This means that the hiring freezes occur with probability 0. Either all firms recruit, or they all lay workers off. Moreover, in symmetric environment, all firms set the same price. Using Lemma 3.1, we know that at a symmetric equilibrium, the employment decision of firms is determined by the value of:

$$\begin{aligned}
 G(N_{t-1}, a_t) &= \left\{ \frac{M}{\nabla_N F((1-s)N_{t-1})} \right\} \{ (1-s)N_{t-1} \cdot \nabla_N S + S((1-s)N_{t-1}, a_t) \\
 &\quad + \mathbb{E}_t [Z(\theta_{t+1}, c)] - (1-s)\delta \cdot \mathbb{E}_t [R(\theta_{t+1}, c) | \mathcal{F}^+] \cdot p^+ \}.
 \end{aligned}$$

$p^+ \in [0, 1]$ is the measure of future states of the world in which there is recruiting in equilibrium in the next period (see proof of Lemma 3.1). I assume that $G(N, a)$ is strictly increasing in N so that the symmetric equilibrium (if it exists) is unique. Then, recruiting occurs in period t in a symmetric equilibrium if and only if $G(N_{t-1}, a_t) < 1$. Therefore, a necessary and sufficient condition to avoid layoffs is $\forall t \geq 0$,

$$\begin{aligned}
 \left\{ \frac{M}{\nabla_N F((1-s)N_{t-1})} \right\} \{ (1-s)N_{t-1} \nabla_N S + S((1-s)N_{t-1}, a_t) + \mathbb{E}_t [Z(\theta_{t+1}, c)] \\
 - (1-s)\delta \mathbb{E}_t [R(\theta_{t+1}, c)] \} \leq 1.
 \end{aligned}$$

I use $\mathbb{E}_t[R(\theta_{t+1}, c)] = \mathbb{E}_t[R(\theta_{t+1}, c)|\mathcal{F}^+] \cdot p^+ + \mathbb{E}_t[R(\theta_{t+1}, c)|\mathcal{F}^-] \cdot p^-$ because $\mathbb{E}_t[R(\theta_{t+1}, c)|\mathcal{F}^-] = 0$, and $p^h = 0$ for all h (using partition defined by (3.26)).

Proof of Lemma 3.2. Assume that $\exists(N^*, a^*) \in (0, 1] \times \mathbb{R}^{++}$, $J(N^*, a^*) < 0$. I apply the Intermediate-Value theorem, given that $J(., a^*) : (0, 1] \rightarrow \mathbb{R}$ is continuous, $\lim_{N \rightarrow 0} J(N, a^*) > 0$, and $J(N^*, a^*) < 0$. This implies that the equation $J(N, a^*) = 0$ admits at least one solution, whose uniqueness derives from the strict monotonicity of $J(., a^*)$ (Assumption 3.6). Given that J is continuously differentiable, and $\nabla_N J \neq 0$, the Implicit Function Theorem indicates that there exist an open interval \mathcal{I} centered at a^* such that for all $a \in \mathcal{I}$, $J(N, a) = 0$ admits a unique solution. The function $N^C : \mathcal{I} \rightarrow (0, 1)$ such that $J(N^C(a), a) = 0$ is therefore well-defined.

Proof of Lemma 3.3. Note that $\cup \mathcal{I} \neq \emptyset$ because there exists at least one open interval that satisfies Lemma 3.2.

Case 1: I assume $\lim_{a \rightarrow +\infty} J(1, a) < 0$. Obviously, $\cup \mathcal{I} \subseteq \mathbb{R}^{++}$, since all $\mathcal{I} \subseteq \mathbb{R}^{++}$. Next, let $a^+ \in \mathbb{R}^{++}$. Then $J(1, a^+) < 0$ because $\lim_{a \rightarrow +\infty} J(1, a) < 0$ and $\nabla_a J > 0$. I can apply the Intermediate-Value theorem as in the proof of Lemma 3.2, to show that $J(N, a^+) = 0$ admits a unique solution. Since \mathbb{R}^{++} is an open interval, I conclude that $\mathbb{R}^{++} \subseteq \cup \mathcal{I}$. Finally, $\mathbb{R}^{++} = \cup \mathcal{I} = \mathcal{A}$.

Case 2: I assume $\lim_{a \rightarrow +\infty} J(1, a) \geq 0$. We also assumed that $\exists(N^*, a^*) \in (0, 1] \times \mathbb{R}^{++}$, $J(N^*, a^*) < 0$. Since $\nabla_N J < 0$, $J(1, a^*) < 0$. Applying the Intermediate-Value theorem to the continuous function $J(1, .)$, I conclude that there exists a unique $a^C \in \{\mathbb{R}^{++}, +\infty\}$, $J(1, a^C) = 0$. I can repeat the proof of Lemma 3.2 with any $a^+ \in (0, a^C)$ to show that $J(N, a^+) = 0$ admits a unique solution, because $\nabla_a J > 0$ so that $J(1, a^+) < 0$. Thus $(0, a^C)$ is one such \mathcal{I} described by Lemma 3.2, and $(0, a^C) \subseteq \cup \mathcal{I}$.

It is also obvious that any $a > a^C$ satisfies $\forall N \in (0, 1]$, $J(N, a) > 0$ (because $\nabla_N J < 0$ and $\nabla_a J > 0$), and cannot belong to any \mathcal{I} . Therefore, a belongs to all $\overline{\mathcal{I}}$, and $[a^C, +\infty) \subseteq \cap \overline{\mathcal{I}} = \overline{\cup \mathcal{I}}$. The set \overline{X} is the complement of set X in \mathbb{R}^{++} . Accordingly, $\cup \mathcal{I} \subseteq [a^C, +\infty) = (0, a^C)$. To conclude, $(0, a^C) = \cup \mathcal{I}$.

Pursuing argument from the proof of Lemma 3.2, the Implicit Function Theorem tells us that $N^C : \mathcal{A} \rightarrow (0, 1)$ is continuously differentiable, and that by combining Assumptions 3.6 and 3.7

$$\nabla_a N^C = \frac{-\nabla_a J}{\nabla_N J} < 0.$$

Proof of Proposition 3.3.

ASSUMPTION 3.10. $D \equiv \sup_{a \in \mathcal{A}} |\nabla_a \theta| < +\infty$, and $\nabla_a^2 \theta$ is small enough to be neglected in my local approximations.

ASSUMPTION 3.11. Assume that the stochastic process $\{a_t\}$ for technology follows an AR(1) process: $a_{t+1} = \rho a_t + z_{t+1}$, with $z \sim N(0, \sigma^2)$. Assume that $\rho \in (0, 1)$ is close enough

to 1 for my local approximations to be valid.

ASSUMPTION 3.12. I assume that σ^2 is small enough for all the k^{th} moments of $N(0, \sigma^2)$, $k \geq 4$, to be small enough for my local approximations to be valid. If $(\nabla_\theta^3 Z - \delta(1-s)\nabla_\theta^3 R) < 0$, I also assume that $\forall \theta \in \mathbb{R}^+$:

$$-\frac{(1 - \delta(1 - s)) \nabla_\theta R + \nabla_\theta X + \nabla_\theta Z}{(\nabla_\theta^3 Z - \delta(1 - s)\nabla_\theta^3 R) \cdot D^2} > \sigma^2.$$

LEMMA 3.4. Under Assumptions 3.11, 3.6, 3.7, 3.8, 3.9, 3.10, 3.12, and $\forall a \in \mathcal{A}$:

- (i) $\nabla_a U < 0$;
- (ii) $\nabla_a U^C < 0$;
- (iii) $\nabla_a U^F > 0$.

PROOF. Combining (3.4) and (3.25), which link employment to labor market tightness under Assumption 3.9, I can express N_t as $N_t = N(\theta_t)$. $N : \mathbb{R}^+ \rightarrow [0, 1]$ is continuous and differentiable, and $N(\theta)$ is given by:

$$N(\theta) = \frac{f(\theta)}{s + (1-s)f(\theta)}. \quad (3.27)$$

In particular $\nabla_\theta N > 0$. The equilibrium in period t is determined by firm's Euler equation (3.16), which I rewrite here for convenience:

$$R(\theta_t, c) + X(\theta_t, c) + \mathbb{E}_t [Z(\theta_{t+1}, c)] - \delta(1-s)\mathbb{E}_t [R(\theta_{t+1}, c)] = J(N(\theta_t), a_t). \quad (3.28)$$

Given that the stochastic process $\{a_t\}_{t=0}^{+\infty}$ for technology is an AR(1) process, I can rewrite $\mathbb{E}_t [\cdot] \equiv \mathbb{E} [\cdot | a^t]$ as $\mathbb{E} [\cdot | a_t]$. Thus, I can write θ_t as a function of a_t : $\theta_t = \theta(a_t)$. I assume that the equilibrium exists and is unique. Therefore, I assume that $\theta : \mathbb{R}^+ \rightarrow \mathbb{R}^+$ is uniquely defined.¹³ I also assume that θ is continuous and differentiable on \mathbb{R}^+ . Thus, I can linearize $\theta(\cdot)$ (using x' to denote variable x in the next period):

$$R(\theta(a'), c) = R(\theta(\rho a + z), c) = R(\theta(\rho a), c) + z \cdot \nabla_\theta R \cdot \nabla_a \theta + z^2 \cdot \{ \nabla_\theta^2 R \cdot (\nabla_a \theta)^2 + \nabla_\theta R \cdot \nabla_a^2 \theta \} + o(z^2).$$

Moreover, $\mathbb{E}[z] = 0$, $\mathbb{E}[z^2] = \sigma^2$, $\mathbb{E}[z^3] = 0$, and neglecting the fourth and higher moments

¹³Mortensen and Nagypál (2007) prove this result formally in a model in which J does not depend on θ —the standard Mortensen and Pissarides (1994) model with constant marginal returns to labor. However, this type of proof based on a fixed-point theorem and Blackwell's sufficient conditions for a contraction would not work here.

of $N(0, \sigma^2)$ (which boils down to neglecting σ^4):

$$\mathbb{E}[R(\theta(a'), c)|a] = \int_{-\infty}^{+\infty} R(\theta(\rho a + z), c) \phi(z) dz \approx R(\theta(\rho a), c) + \{\nabla_{\theta}^2 R \cdot (\nabla_a \theta)^2 + \nabla_{\theta} R \cdot \nabla_a^2 \theta\} \sigma^2.$$

Next, neglecting the second-order term $\nabla_a^2 \theta$:

$$\begin{aligned} \mathbb{E}[R(\theta(a'), c)|a] &\approx R(\theta(\rho a), c) + \{\nabla_{\theta}^2 R \cdot (\nabla_a \theta)^2\} \sigma^2 \\ &\approx R(\theta(a), c) - (1 - \rho)a \nabla_{\theta} R \cdot \nabla_a \theta + \{\nabla_{\theta}^2 R \cdot (\nabla_a \theta)^2\} \sigma^2 + o((1 - \rho)a). \end{aligned}$$

To be precise, I neglect the term factored by $(1 - \rho)\sigma^2$ that would arise if I wrote the Taylor approximation of $\nabla_{\theta}^2 R$ around $\nabla_{\theta}^2 R(\theta(a), c)$, and evaluated it at $\rho\theta(a)$. Neglecting this term, and second-order (and above) terms $\nabla_a^2 \theta$ yields:

$$\sigma^2 \{\nabla_{\theta}^2 R \cdot (\nabla_a \theta)^2\}|_{\theta=\rho\theta(a)} \approx \sigma^2 \{\nabla_{\theta}^2 R \cdot (\nabla_a \theta)^2\}|_{\theta=\theta(a)}.$$

Following the same procedure, I approximate:

$$\mathbb{E}[Z(\theta(a'), c)|a] \approx Z(\theta(a), c) - (1 - \rho)a \nabla_{\theta} Z \cdot \nabla_a \theta + \{\nabla_{\theta}^2 Z \cdot (\nabla_a \theta)^2\} \sigma^2 + o((1 - \rho)a).$$

These approximations allow me to rewrite the equilibrium condition (3.28) for any $a \in \mathcal{A}$. ρ is close enough to 1 so that I can abstract from all terms in $(1 - \rho)$. Taking derivative with respect to a and neglecting the second-order term $\nabla_a^2 \theta$:

$$[(1 - \delta(1 - s)) \nabla_{\theta} R + \nabla_{\theta} X + \nabla_{\theta} Z + \{\nabla_{\theta}^3 Z - \delta(1 - s) \nabla_{\theta}^3 R\} \cdot (\nabla_a \theta)^2 \sigma^2 - \nabla_N J \nabla_{\theta} N] \nabla_a \theta = \nabla_a J.$$

We have $\nabla_{\theta} R > 0$, $\nabla_{\theta}(X + Z) > 0$, $\nabla_N J < 0$, $\nabla_a J > 0$, and $\nabla_{\theta} N < 0$. Using Assumption 3.12, this implies:

$$[(1 - \delta(1 - s)) \nabla_{\theta} R + \nabla_{\theta} X + \nabla_{\theta} Z + \{\nabla_{\theta}^3 Z - \delta(1 - s) \nabla_{\theta}^3 R\} \cdot (\nabla_a \theta)^2 \sigma^2 - \nabla_N J \nabla_{\theta} N] > 0.$$

Then I can conclude that for any $a \in \mathbb{R}^+$, $\nabla_a \theta > 0$. Stepping back to:

$$[(1 - \delta(1 - s)) \nabla_{\theta} R \nabla_{\theta} X + \nabla_{\theta} Z + \{\nabla_{\theta}^3 Z - \delta(1 - s) \nabla_{\theta}^3 R\} \cdot (\nabla_a \theta)^2 \sigma^2] \nabla_a \theta = \nabla_a J(N(\theta(a)), a).$$

I conclude that in this stochastic environment, and for any $a \in \mathbb{R}^+$, $\nabla_a J(N(\theta(a)), a) > 0$.

Next, rewriting the gross marginal profit J for any $a \in \mathcal{A}$:

$$\begin{aligned} J(N(a), a) &= J(N^C(a) - N^F(a), a) - J(N^C(a), a) \\ &= \int_{N^C(a)}^{N^C(a) - N^F(a)} \nabla_N J(N, a) dN \\ &= \int_0^{N^F(a)} \nabla_n J(N^C(a) - n, a) dn, \end{aligned}$$

where the function $N^F(\cdot)$ is simply $N^F(\cdot) = N^C(\cdot) - N(\cdot)$. Differentiating with respect to a :

$$\nabla_a J(N(a), a) = \int_0^{N^F(a)} \nabla_{n,a} J(N^C(a) - n, a) dn - \nabla_a N^F \cdot \nabla_N J(N(a), a).$$

Using $\nabla_a J(N(a), a) > 0$, $\nabla_{n,a} J(N^C(a) - n, a) \leq 0$, and $\nabla_N J(N, a) < 0$, it follows that $\nabla_a N^F > 0$. We also proved that $\nabla_a N > 0$, and we know that $\nabla_a N^C < 0$. To conclude, it suffices to notice that $U(a) = 1 - (1 - s)N(a)$, $U^F(a) = s \cdot N(a) + N^F(a)$, and $U^C(a) = 1 - N^C(a)$. \square

Appendix 3.B Extension to a Two-State Markov-Chain Productivity Process

I assume that technology follows a 2-state Markov chain with state space $\{a_L, a_H\}$ and an ergodic transition matrix $\mathbf{\Lambda}$. I assume that $0 < a_L < a_H$, and that there is job rationing in both states, so that $U_L^C > 0$ and $U_H^C > 0$. Under Assumption 3.9, since technology follows a Markov process, all labor market variables at time t solely depend on the realization of technology in the current period. I note θ_i , N_i , U_i , U_i^C , and U_i^F the value of these variables when technology $a_t = a_i$.

ASSUMPTION 3.13 (FOSC). Consider a Markov chain with state space $\{a_1, \dots, a_n\} \in \mathbb{R}^n$ and $a_1 < \dots < a_n$. Then $\forall i, j = 1 \dots n, i > j$:

$$\mathbb{P}\{.\mid a_i\} \succeq_{FOSC} \mathbb{P}\{.\mid a_j\}, \quad (3.29)$$

where $\mathbb{P}\{.\mid a\}$ is the conditional transition probability in state a , and \succeq_{FOSC} indicates first-order stochastic dominance.

This assumption implies that the matrix $\mathbf{\Lambda}$ preserves ordering of vectors.

LEMMA 3.5. Let $\mathbf{\Lambda}$ be the $n \times n$ transition matrix of a Markov chain that satisfies Assumption 3.13. Let $\mathbf{X} = [X_i]_{i=1, \dots, n}$ be such that $X_1 < \dots < X_n$. Let $\mathbf{Y} = (Y_i)_{i=1, \dots, n}$ be

defined by $\mathbf{Y} = \mathbf{\Lambda}\mathbf{X}$. Then the ordering of vector \mathbf{X} is preserved after multiplication by the transition matrix $\mathbf{\Lambda}$: $Y_1 < \dots < Y_n$.

PROOF. Assume that $\mathbf{\Lambda} = [\Lambda_{i,j}]_{i,j=1,\dots,n}$ satisfies Assumption 3.13. Then by definition of first-order stochastic dominance, for $i > j$, and for any $s = 1, \dots, n$:

$$\sum_{q \geq s} \Lambda_{i,q} \geq \sum_{q \geq s} \Lambda_{j,q}. \quad (3.30)$$

I denote $X_0 \equiv 0$. For $i = 1, \dots, n$:

$$\begin{aligned} Y_i &= \sum_{s=1}^n \Lambda_{i,s} X_s \\ &= \sum_{s=1}^n \left(\sum_{q=s}^n \Lambda_{i,q} \right) (X_s - X_{s-1}). \end{aligned}$$

Therefore for $i > j$:

$$Y_i - Y_j = \sum_{s=1}^n \left[\left(\sum_{q=s}^n \Lambda_{i,q} \right) - \left(\sum_{q=s}^n \Lambda_{j,q} \right) \right] (X_s - X_{s-1}).$$

The terms in brackets are always nonnegative by assumption (see (3.30)). The terms in parenthesis are nonnegative because of the ordering of \mathbf{X} . Hence, $Y_i > Y_j$. \square

ASSUMPTION 3.14. For all $(\theta, c) \in \mathbb{R}^+ \times \mathbb{R}^+$, $\nabla_{\theta} X > 0$.

This assumption, which is satisfied for all the specific wage schedules studied in this paper (Section 4.2) implies that wages are higher when the current labor market is tighter. This is a natural assumption given that workers' position is more favorable when the labor market is tight. In a two-state world, the main result of the paper (Proposition 3.3) obtains for any stochastic process for technology satisfying Assumption 3.13.

PROPOSITION 3.4. Under Assumption 3.13:

- (i) $U_H < U_L$;
- (ii) $U_H^C < U_L^C$;
- (iii) $U_H^F > U_L^F$.

PROOF. In this world, equilibrium condition (3.18) is:

$$[R(\theta_i, c)] = [J(N_i, a_i)] - [X(\theta_i, c)] - \mathbf{\Lambda} [Z(\theta_i, c)] + \delta(1-s)\mathbf{\Lambda} [R(\theta_i, c)],$$

where $[X_i]$ is the column vector stacking up the X_i , $i = L, H$. Iterating forward:

$$[R(\theta_i, c)] = \left(\sum_{j=0}^{+\infty} \delta^j (1-s)^j \mathbf{\Lambda}^j \right) \{ [J(N_i, a_i)] - [X(\theta_i, c)] - \mathbf{\Lambda} [Z(\theta_i, c)] \}.$$

Let

$$\mathbf{\Gamma} \equiv (1 - \delta \cdot (1-s))^{-1} \left(\sum_{j=0}^{+\infty} \delta^j (1-s)^j \mathbf{\Lambda}^j \right).$$

Notice that $\mathbf{\Gamma}$ is well defined because $\mathbf{\Lambda}$ is ergodic. Thus, all eigenvalues are in the unit circle, and $\sum_{j=0}^{+\infty} \delta^j (1-s)^j \mathbf{\Lambda}^j$ converges. Since $\mathbf{\Lambda}$ satisfies Assumption 3.13, for all $i \geq 0$, $\mathbf{\Lambda}^i$ satisfies Assumption 3.13 as well (note that $\mathbf{\Lambda}^i$ is also a transition matrix). Thus, $\mathbf{\Gamma}$ also satisfies Assumption 3.13 and preserves ordering of vectors as described in Lemma 3.5.

I now reason by contradiction. Assume that $\theta_H < \theta_L$. Then $N_H < N_L$ and $J(N_H, a_H) > J(N_L, a_L)$. Moreover, $X(\theta_H, c) < X(\theta_L, c)$, and $(X + Z)(\theta_H, c) < (X + Z)(\theta_L, c)$. Noting $X_i \equiv X(\theta_i, c)$, $Z_i \equiv Z(\theta_i, c)$, I can rewrite:

$$\begin{aligned} X_H + \mathbf{\Lambda} [Z_i] &= \lambda_{H,H} (X_H + Z_H) + (1 - \lambda_{H,H})(X_L + Z_L) + (1 - \lambda_{H,H})(X_H - X_L) \\ X_L + \mathbf{\Lambda} [Z_i] &= (1 - \lambda_{L,L})(X_H + Z_H) + \lambda_{L,L} (X_L + Z_L) + (1 - \lambda_{L,L})(X_L - X_H). \end{aligned}$$

By Assumption 3.13: $\lambda_{H,H} > 1 - \lambda_{L,L}$. Thus, $X_H + \mathbf{\Lambda} [Z_i] < X_L + \mathbf{\Lambda} [Z_i]$. Since L preserves ordering of vectors, I infer that $R(\theta_H, c) > R(\theta_L, c)$ which implies $\theta_H > \theta_L$. I reach a contradiction. Thus, $a_H > a_L \Rightarrow \theta_H > \theta_L$. This means that $X_H + Z_H > X_L + Z_L$, $X_H > X_L$. Therefore, it must be that $J(N_H, a_H) > J(N_L, a_L)$, otherwise I would reach the contradiction that $\theta_H < \theta_L$, as in the first part of the proof. Proceeding as in the end of the proof of Proposition 3.3 yields the results. \square

However, this result does not generalize to a world in which technology follows a n -state Markov chain. Assume that technology follows a 3-state Markov chain with transition matrix:

$$\mathbf{\Lambda} = \begin{bmatrix} 0.99 & 0.01 & 0 \\ 0 & 0.01 & .99 \\ 0 & 0 & 1 \end{bmatrix} \quad (3.31)$$

with $a_1 < a_2 < a_3$, and a_3 sufficiently larger than a_2 , and a_1 very close to a_2 , and $a_i \in \mathcal{A}$ for $\forall i$. Proposition 3.4 may not hold in this case. In state 2, firms recruit a lot more than in state 1, even though technology levels are close in both states, because they anticipate that they are very likely to be in state 1 next period. In state 3, technology is high, the labor market will be tight and recruiting costly. Therefore, firms substitute future recruiting to the current period, in which the labor market is more slack. Because the recruiting activity

is a lot higher in state 2 than in state 1, total unemployment is much lower, even though cyclical unemployment in both states are close. Consequently, frictional unemployment must be much lower in state 2 than in state 1.

Appendix 3.C Graphs

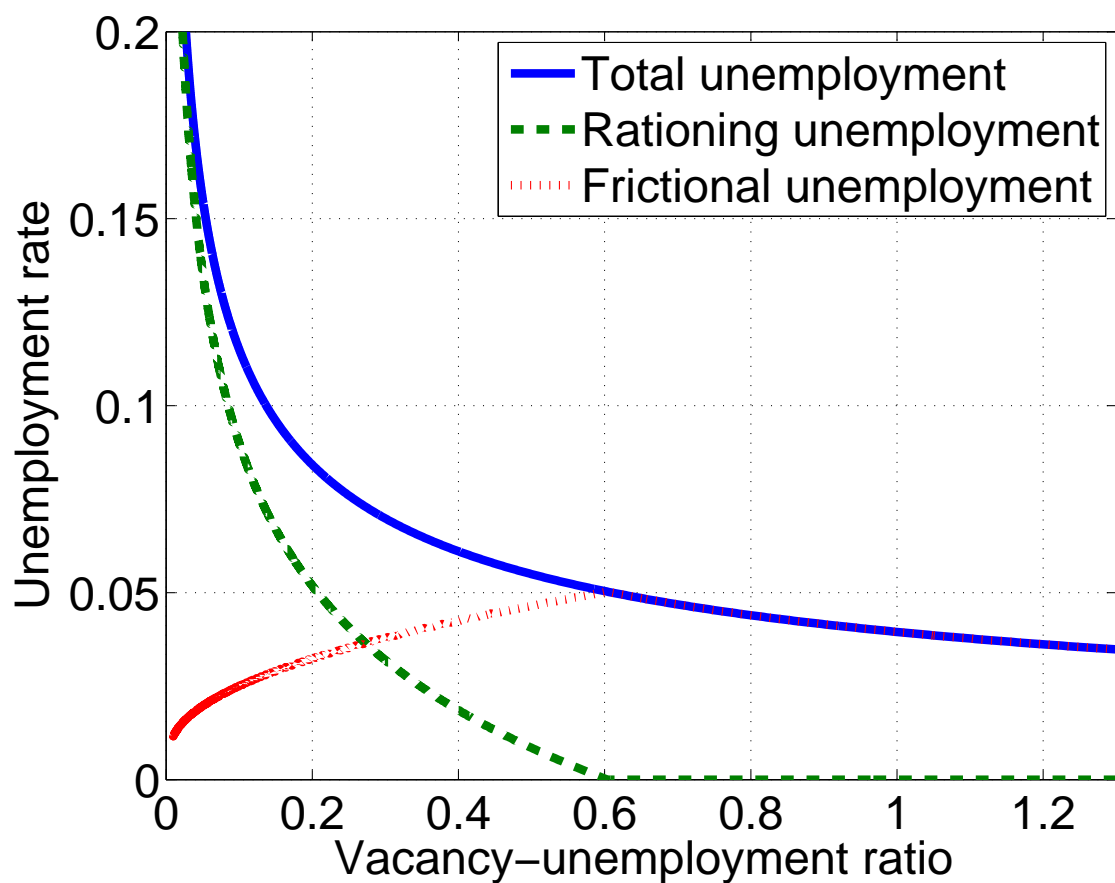


Figure 3.1: Beveridge curve from calibrated model. This graph is obtained by computing a continuum of steady-state equilibria in the labor market, associated with a continuum of realizations of technology. I solve for total unemployment from a system of three equations: (3.4), (3.25), and the steady-state version of (5.4). I can determine cyclical unemployment from (5.3), and obtain frictional unemployment from the difference between these two series.

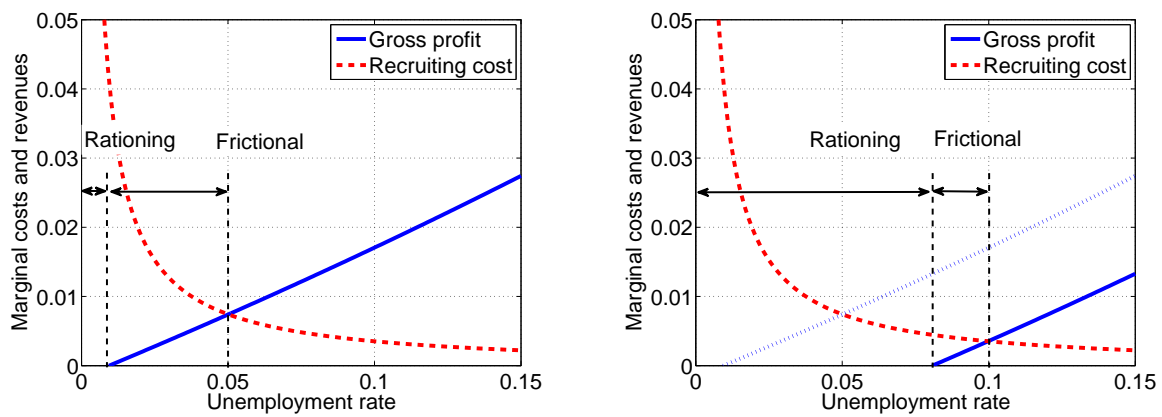


Figure 3.2: Steady-state equilibrium in a model with job rationing. This graph describes a steady-state equilibrium in the model of job rationing presented in Chapter 5. It describes the decomposition of unemployment into rationing unemployment and frictional unemployment for two different realizations of technology. It is obtained by plotting the recruiting cost $R(\theta, c)$ and the gross marginal profit (5.1) for a continuum of unemployment rates.

Chapter 4

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

4.1 Introduction

There is a large number of models in the search-and-matching literature, but the general framework presented in Chapter 3 nests as special cases three classes of influential models from the search-and-matching literature: the canonical model with Nash bargaining, its variant with rigid wages, and its variant with diminishing marginal returns to labor and intrafirm bargaining. These models differ along two dimensions: production function and wage-setting mechanism. Using the framework developed in Chapter 3, I show in this chapter that critically, none of these models satisfy the job rationing property. In other words, there is no unemployment without positive recruiting costs in these models.

This fundamental property is highlighted on Figure 4.1, which compares across models how steady-state unemployment evolves when recruiting costs diminish. The MP model is the canonical search-and-matching model with Nash bargaining. In the MP model, its variant with rigid wages, and its variant with diminishing marginal returns to labor, jobs are not rationed. Therefore, unemployment converges to 0 when recruiting costs converge to 0. The model with rigid wages and diminishing marginal returns to labor is described in Chapter 5. This model does satisfy the job rationing property. Since jobs are rationed, some unemployment, which I call rationing unemployment, may prevail even when recruiting costs converge to zero. On Figure 4.1, it is clear that when $c = 0$, unemployment remains positive only in the search-and-matching model combining both rigid wages and diminishing marginal returns to labor.

The absence of job rationing in existing search-and-matching models is critical because without it, all unemployment is frictional. The absence of rationing unemployment has important implications for the impact of labor market policies on unemployment. Policies improving matching and increasing the search effort of the unemployed are likely to always

reduce unemployment; on the other hand, direct job creation by the government is likely to have no effect on unemployment. Introducing job rationing into a search-and-matching framework offers a more nuanced theory of unemployment over the business cycle. As we saw in Chapter 3, rationing unemployment composes most of unemployment in recessions; frictional unemployment composes all of unemployment in expansions; therefore the effectiveness of labor market policies are likely to depend on the state of the labor market: policies improving matching and increasing the search effort of the unemployed is likely to reduce unemployment in expansions but not in recessions; on the other hand, direct job creation by the government is likely to have no effect on unemployment in expansions but reduce unemployment in recessions.

It is important to understand why there is no job rationing in the existing models from the literature. The canonical model features atomistic firms in which the marginal product of labor remains above the value of unemployment for workers (for example, Mortensen and Pissarides 1994, Pissarides 2000). Once search costs are sunk, matches always generate a positive surplus, which is shared between firm and worker by Nash bargaining over wages. When recruiting costs converge to zero, the net profit from a match is positive for any level of employment. Consequently, firms enter the labor market until all the labor force is employed.

The property that unemployment disappears when recruiting costs converge to zero also holds when rigid wages are introduced into the model (for example, Shimer 2004, Hall 2005a). This is because rigid wages are solely a way to divide the surplus between firms and workers; thus, they always lie between the marginal product of labor, which is independent of employment, and the value of unemployment for workers. For the same reason, this property also applies in large-firm models with rigid wages in which (i) production functions exhibit constant marginal returns to labor (for example, Blanchard and Galí 2008); or (ii) production functions exhibit diminishing marginal returns to labor but capital adjusts immediately to employment (for example, Gertler and Trigari 2009).

Lastly, this property holds in large-firm search-and-matching models with diminishing marginal returns to labor (for example, Cahuc and Wasmer 2001, Elsby and Michaels 2008). This is because these models use Stole and Zwiebel's (1996a) wage-setting mechanism, so the wage is derived from Nash bargaining over surplus from the marginal worker-firm match. Therefore, without recruiting costs, the wage remains below the marginal product of labor for any level of employment.¹ To conclude, neither wage rigidity nor diminishing marginal returns to labor alone suffices to introduce job rationing into the model.

¹This result also holds in the model proposed by Rotemberg (2008)—a variant of the search-and-matching model in which large, monopolistic firms Nash-bargain wages with individual workers.

4.2 Standard Mortensen-Pissarides Model (MP Model)

In this section, I specialize my general model to the standard MP framework (for example, Pissarides 2000, Shimer 2005).² To do so, I make the following assumptions.

ASSUMPTION 4.1 (Perfect competition). $M = 1$.

ASSUMPTION 4.2 (Constant returns to labor). $F(N_t, a_t) = a_t \cdot N_t$.

ASSUMPTION 4.3. There exists $\beta \in (0, 1)$ such that the wage $W_t(i)$ paid by firm i in period t is given by (3.7) where:

- (i) $S(N_t(i), a_t) = 0$;
- (ii) $X(\theta_t, c) = c \cdot \frac{\beta}{1 - \beta} \cdot \frac{1}{q(\theta_t)}$;
- (iii) $Z(\theta_{t+1}, c) = c \cdot \frac{\beta}{1 - \beta} \cdot \delta \cdot (1 - s) \cdot \left(\theta_{t+1} - \frac{1}{q(\theta_{t+1})} \right)$.

LEMMA 4.1 (Equivalence with Nash bargaining). *Assume that wages are bargained each period, and that the wage $W_t(i)$ in period t in firm i is determined by the generalized Nash bargaining solution. Let β be a worker's bargaining power. Then $W_t(i)$ is given by Assumption 4.3.*

The bargaining solution divides surplus from the match between the worker and firm, with the worker keeping a fraction $\beta \in (0, 1)$ of the surplus. In this setting, a firm's surplus from an established relationship is simply given by the hiring cost $c/q(\theta_t)$, since a firm can always immediately replace a worker at that cost during the matching period. When labor market tightness θ_t is high, many firms compete for few unemployed workers. Unemployed workers can find a job quickly, but it takes time for a firm to find a worker. Since a worker's outside option improves relative to a firm's outside option, the wage offered to workers increases. Even though this model is not specified exactly like the canonical model and the wage equation does not take the standard form, their labor market equilibria are virtually identical.³

²Similar results could be obtained with search-and-matching models using alternative bargaining procedure to divide the surplus between firm and worker (for example, Hall and Milgrom 2008).

³The equilibrium condition arising from a firm's Euler equation in this model can be written as:

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

which is comparable to equation (6) in Shimer (2005) since I assume $\lambda = 1$ (an aggregate shock occurs each period), $z = 0$, $1 + r + s \approx 1$, and $\mathbb{E}_t[\theta_{t+1}] \approx \theta_t$ when a_t follows a random walk.

Using the notation defined in Section 3.3, gross marginal profit becomes

$$J(N_t, a_t) = a_t \quad (4.1)$$

because $S(N_t, a_t) = 0$. Since the gross marginal profit satisfies neither the first nor the second condition of Assumption 3.6, all workers would be employed if there were no recruiting costs.

PROPOSITION 4.1 (Full employment in MP model). *Under Assumptions 4.1, 4.2, and 4.3, when $c \rightarrow 0$, $N_t \rightarrow 1$, $\forall t \geq 0$.*

Marginal product of labor is independent of employment, and always greater than the value of unemployment for workers. Even without recruiting costs, matches always generate a positive surplus, which is divided between firm and worker by Nash bargaining over wages. Without matching frictions, the firm faces no costs in creating a match, which implies that the net profit from a match is always positive. As a consequence, firms enter the labor market until all the labor force is employed. As a direct consequence of the absence of job rationing, all unemployment is frictional in the MP model.

4.3 Mortensen-Pissarides Model with Sticky Real Wages (MPS Model)

I now show that introducing wage rigidity in the MP model does not suffice to introduce job rationing. Keeping Assumptions 4.1 and 4.2, I replace the Nash-bargaining assumption by a wage rule that only partially adjusts to technology shocks. Shimer (2004) and Hall (2005a) study this type of MP model with sticky wages (MPS model) to demonstrate that rigid wages help amplify shocks.⁴ The wage schedule borrows Blanchard and Galí's (2008) specification.

ASSUMPTION 4.4 (Partially rigid wage). There exists $\gamma \in [0, 1]$ and $w_0 \in \mathbb{R}^+$ such that the wage $W_t(i)$ paid by firm i in period t is given by (3.7) where:

- (i) $S(N_t(i), a_t) = w_0 \cdot a_t^\gamma$;
- (ii) $X(\theta_t, c) = 0$;
- (iii) $Z(\theta_{t+1}, c) = 0$.

⁴Similar results could be obtained in large-firm models with rigid wages in which (i) production functions exhibit constant marginal returns to labor (for example, Blanchard and Galí 2008); or (ii) production functions exhibit diminishing marginal returns to labor but capital adjusts immediately to employment (for example, Gertler and Trigari 2009).

With $\gamma = 0$, wages are completely rigid, which corresponds to Shimer's (2004) specification. Under these assumptions, the gross marginal profit becomes

$$J(N_t, a_t) = a_t - w_0 \cdot a_t^\gamma. \quad (4.2)$$

As for the MP model, the gross marginal profit is independent of employment, and does not satisfy Assumption 3.6 for any $\gamma \in [0, 1]$. As a direct consequence of the absence of job rationing, all unemployment is frictional in the MPS model.

PROPOSITION 4.2 (Full employment in MPS model). *Assume that $w_0 \leq a_t^{1-\gamma}$, $\forall t \geq 0$. Under Assumptions 4.1, 4.2, and 4.4, when $c \rightarrow 0$, $N_t \rightarrow 1$, $\forall t \geq 0$.*

When a worker and a firm meet, they match if the wage is between the two parties' reservation levels. When recruiting costs converge to 0, the firm's reservation level is the marginal product of labor, which is independent of employment and greater than the rigid wage level by assumption. Hence, if one job is profitable, infinitely many jobs would be profitable, and the economy would operate at full employment.

This results can be illustrated with a simple diagram shown in Figure 4.2. This diagram represents the steady-state equilibrium condition on a plane with unemployment on the x-axis and marginal profit on the y-axis. The gross marginal profit $J(N, a)$ is independent of employment and is represented by the horizontal, solid line. The downward-sloping, dotted line is the marginal cost of hiring $(1 - (1-s)\delta)R(\theta, c)$. Total unemployment is obtained at the intersection of the gross marginal profit and marginal hiring cost curves. The gross marginal profit is positive for any employment level, and any technology such that $w_0 \leq a_t^{1-\gamma}$. When recruiting cost $c = 0$, the marginal hiring cost converges to 0 for any positive employment level, while the gross marginal profit is positive. Therefore, firms keep on hiring as long as unemployment is positive. Hence, there is no job rationing in this model. To conclude, wage rigidity does not suffice to introduce job rationing.

4.4 Large-Firm Model with Stole-Swiebel Intrafirm Bargaining (SZ Model)

In this section, I show that introducing diminishing marginal returns to labor in the MP model does not suffice to introduce job rationing. I specialize my general model to a large-firm, search-and-matching model with the intrafirm bargaining procedure of Stole and Zwiebel (1996a) and Stole and Zwiebel (1996b).⁵ I assume perfect competition (Assumption 4.1), and make two assumptions about the production function and wage-setting.

⁵The model presented here shares features with large-firm models studied in Cahuc and Wasmer (2001), Cahuc et al. (2008), and Elsby and Michaels (2008).

ASSUMPTION 4.5 (Diminishing marginal returns to labor). There exists $\alpha \in [0, 1]$ such that $F(N_t, a_t) = a_t \cdot N_t^\alpha$.

ASSUMPTION 4.6. There exists $\beta \in (0, 1)$ such that the wage $W_t(i)$ paid by firm i in period t is given by (3.7) where:

- (i) $S(N_t(i), a_t) = \beta \frac{\alpha \cdot a_t \cdot N_t(i)^{\alpha-1}}{1 - \beta(1 - \alpha)}$;
- (ii) $X(\theta_t, c) = 0$;
- (iii) $Z(\theta_{t+1}, c) = c \cdot (1 - s)\delta \cdot \beta \cdot \theta_{t+1}$.

LEMMA 4.2 (Equivalence with Stole and Zwiebel's (1996a) bargaining). *Assume that wages are bargained each period, and that the wage $W_t(i)$ in period t in firm i is determined by Stole and Zwiebel's (1996a) bargaining solution. Let β be a worker's bargaining power. Then $W_t(i)$ is given by Assumption 4.6.*

The gross marginal profit becomes

$$J(N_t, a_t) = \left[\frac{1 - \beta}{1 - \beta(1 - \alpha)} \right] a_t \cdot \alpha \cdot N_t^{\alpha-1},$$

and satisfies the first condition in Assumption 3.6 since $\nabla_N J < 0$. However, the gross marginal profit $J(N_t, a_t)$ always remains positive in spite of diminishing marginal returns to labor. This is because the wage falls sufficiently when employment increases and the marginal product of labor decreases. Hence, there is no job rationing and all unemployment is frictional.

PROPOSITION 4.3 (Full employment in SZ model). *Under Assumptions 4.1, 4.5, and 4.6, when $c \rightarrow 0$, $N_t \rightarrow 1$, $\forall t \geq 0$.*

Intrafirm bargaining implies that the wage is derived from Nash bargaining over the surplus from the marginal worker-firm match. When recruiting costs are zero, the wage remains below the marginal product of labor for any employment level, and it is profitable for firms to continue hiring until everybody is employed. Thus, introducing downward-sloping demand for labor is not sufficient for obtaining job rationing and positive cyclical unemployment.

4.5 Concluding Remarks

This chapter showed that three influential search-and-matching models were special cases of the general model I developed in Chapter 3: the canonical Mortensen-Pissarides model,

its rigid-wage variant, and its large-firm variant with intrafirm bargaining and diminishing marginal returns to labor. However, there is no job rationing in these models: without recruiting costs, unemployment disappears.

The first question prompted by these results is: What type of assumptions would introduce job rationing into the general model presented in Chapter 3? I address this question in Chapter 5, and specialize the production function and wage schedule of my general model to show how a combination of wage rigidity and diminishing marginal returns to labor actually yields job rationing. The wage-rigidity and diminishing-returns assumptions had been studied separately in the literature, but only their interaction can generate job rationing.

The second question prompted by these results is: How much does the absence of job rationing in the models of the literature matter? In fact, the absence of job rationing in existing search-and-matching models is critical because without it, all unemployment is frictional. This property has several important implications for the impact of labor market policies on unemployment: (i) policies improving matching are likely to always reduce unemployment; (ii) direct job creation by the government is likely to have no effect on unemployment; (iii) policies reducing the search effort of the unemployed are likely to always increase unemployment. This dissertation offers a more nuanced theory of unemployment over the business cycle: job rationing explains most of unemployment in recessions; matching frictions explains all of unemployment in expansions. These results suggest that the effectiveness of labor market policies depends on the state of the labor market: (i) policies improving matching reduce unemployment in expansions but not in recessions; (ii) direct job creation by the government has no effect on unemployment in expansions but reduces unemployment in recessions; (iii) policies reducing the search effort of the unemployed, such as a generous unemployment insurance, increase unemployment in expansions but have no effect on unemployment in recessions. From a normative standpoint, these results imply that policymakers should adapt labor market policies to the state of the labor market. I flesh out this argument in Chapter 6.

Appendix 4.A Proofs

Proof of Lemma 4.1. 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.

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

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:

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

In this setting, the firm's surplus from an established relationship is simply given by the hiring cost $c/q(\theta_t)$, 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:

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

Thus, the solution of the bargaining game is

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

Proof of Lemma 4.2. The wage schedule $W(N_t)$ is determined by Nash bargaining over the marginal surplus from a match. I assume that the wage that solves the bargaining problem does not generate layoffs. This simplifies the analysis. I verify at the end of the derivation that the solution actually satisfies this condition. As in the proof of Lemma 4.1, the surplus to the representative household of having a marginal member employed in an established job relationship is:

$$\mathbb{L}_t - \mathbb{U}_t = W_t + \delta \cdot \mathbb{E}_t [(1 - s) \cdot (1 - f(\theta_{t+1})) (\mathbb{L}_{t+1} - \mathbb{U}_{t+1})]. \quad (4.3)$$

Following the derivations in Section 3.2.5, the marginal profit to the firm of having an additional worker, once the relationship is established, is:

$$\mathbb{J}_t = \nabla_N F - W_t - N_t \nabla_N W + (1 - s) \cdot \delta \cdot \mathbb{E}_t \left[\frac{c}{q(\theta_{t+1})} \right]. \quad (4.4)$$

This marginal profit corresponds to the surplus of the established relationship accruing to the firm. Note that firm maximizes profit taken the wage rule as given, and that the first-order conditions derived in Section 3.2.5 (by assumption, $M = 1$, i.e. $\epsilon \rightarrow +\infty$, so that $P_t(i) = P_t$

and $\nu_t = 1$) imply that

$$\mathbb{J}_t = \frac{c}{q(\theta_t)}. \quad (4.5)$$

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:

$$\mathbb{L}_t - \mathbb{U}_t = \frac{\beta}{1 - \beta} \cdot \mathbb{J}_t. \quad (4.6)$$

Combining (4.3)-(4.6), I can derive a differential equation in the wage schedule:

$$W(N_t) + \beta N_t \nabla_N W = \beta [\nabla_N F + c \cdot (1 - s) \cdot \delta \cdot \mathbb{E}_t [\theta_{t+1}]].$$

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

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

Proof of Proposition 4.1. Plugging the wage schedule assumed in Assumption 4.3 into the equilibrium condition (3.16) derived in the general case yields:

$$\frac{c}{q(\theta_t)} + c \cdot \delta \cdot (1 - s) \beta \mathbb{E}_t [\theta_{t+1}] = (1 - \beta) a_t + c \delta \cdot (1 - s) \mathbb{E}_t \left[\frac{1}{q(\theta_{t+1})} \right]. \quad (4.7)$$

No aggregate shock. Without aggregate shocks, the following equilibrium condition determines implicitly θ as a function of c :

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

Assume that $\exists L \in \mathbb{R}^+$, $\theta(c) < L$ for all c . Then (since $1/q(\cdot)$ is increasing in θ):

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

and for $0 < c < \frac{1}{\lambda} \cdot (1 - \beta) \cdot a$, the equilibrium condition cannot hold. Therefore:

$$\lim_{c \rightarrow 0} \theta(c) = +\infty.$$

With aggregate shocks. I assume that the stochastic process $\{a_t\}_{t=0}^{+\infty}$ is a Markov process. Then Mortensen and Nagypál (2007) show that there exists a unique function $\theta : \mathbb{R}^+ \rightarrow \mathbb{R}^+$, continuous and differentiable, that solves this sequence of equations (4.7). I use the standard specification for the matching function $h(U_t, V_t) = \omega U_t^\eta V_t^{1-\eta}$, such that $c/q(\theta_t) = c \cdot \omega \cdot \theta_t^\eta$. Given $\{a_t\}$, the stochastic process for equilibrium labor market tightness $\{\theta_t\}_{t=0}^{+\infty}$ is unique (Mortensen and Nagypál 2007). I now show that $\{\hat{\theta}_t\}_{t=0}^{+\infty}$ whose time t elements are measurable with respect to a^t , and are defined for all $t \geq 0$ by

$$\hat{\theta}_t = \frac{1 - \beta}{c\delta(1 - s)\beta} \times \frac{a_{t-1}}{\mathbb{E}_{t-1}[a_t]} \times a_t$$

satisfies this equation when recruiting costs $c \rightarrow 0$ (I noted $a_{-1} = 1, \mathbb{E}_{-1}[a_0] = 1$). With such a stochastic process for labor market tightness:

$$\begin{aligned} c/q(\theta_t) &\sim c^{1-\eta} \cdot \psi_1(a^t) \\ \mathbb{E}_t[c/q(\theta_{t+1})] &\sim c^{1-\eta} \cdot \psi_2(a^t) \\ c\mathbb{E}_t[\theta_{t+1}] &\sim \frac{1 - \beta}{\delta(1 - s)\beta} \cdot a_t. \end{aligned}$$

Thus, when $c \rightarrow 0$:

$$\begin{aligned} c/q(\theta_t) &\rightarrow 0 \\ \mathbb{E}_t[c/q(\theta_{t+1})] &\rightarrow 0 \\ c\mathbb{E}_t[\theta_{t+1}] &\rightarrow \frac{1 - \beta}{\delta(1 - s)\beta} \cdot a_t. \end{aligned}$$

It is clear that as $c \rightarrow 0$, this process for labor market tightness does solve the equilibrium condition. Therefore, when $c \rightarrow 0$, $\theta_t \rightarrow +\infty$, $f(\theta_t) \rightarrow 1$, $U_t \rightarrow s$, $N_t \rightarrow 1$, and $W_t \rightarrow (1 - \beta) \cdot a_t$.

Proof of Proposition 4.2. I assume that the stochastic process $\{a_t\}_{t=0}^{+\infty}$ is a Markov process. Plugging the wage schedule assumed in Assumption 4.4 into the general equilibrium condition (3.16) yields:

$$\frac{c}{q(\theta_t)} = a_t - w_0 + c \cdot \delta \cdot (1 - s) \mathbb{E}_t \left[\frac{1}{q(\theta_{t+1})} \right]. \quad (4.8)$$

The stochastic process $\{\theta_t\}_{t=0}^{+\infty}$ that solves the sequence of equations (4.8) satisfies $\theta_t = \theta(a_t, c)$

for all t , where $\theta : \mathbb{R}^+ \times \mathbb{R}^{++} \rightarrow \mathbb{R}^+$ is defined implicitly by:

$$\frac{1}{q(\theta(a, c))} = \mathbb{V}(a, c)$$

and the value function \mathbb{V} is defined recursively by

$$\mathbb{V}(a_t, c) = \frac{a_t - w_0}{c} + \delta \cdot (1 - s) \mathbb{E} [\mathbb{V}(a_{t+1}, c) | a_t].$$

For all $(a, c) \in \mathbb{R}^+ \times \mathbb{R}^{++}$:

$$\mathbb{V}(a, c) \geq \frac{a - w_0}{c}.$$

Therefore, for all $a \in \mathbb{R}^+$, $\lim_{c \rightarrow 0} \mathbb{V}(a, c) = +\infty$. Using the standard matching function specification: $1/q(\theta) = \omega \cdot \theta^n$. Therefore, for all $a \in \mathbb{R}^+$:

$$\lim_{c \rightarrow 0} \theta(a, c) = +\infty.$$

To conclude, equilibrium employment and unemployment can be written as $N_t = N(a_t, c)$ and $U_t = U(a_t, c)$, using equations (3.25) and (3.4). Then, for all $a \in \mathbb{R}^+$, $\lim_{c \rightarrow 0} N(a, c) = 1$ and $\lim_{c \rightarrow 0} U(a, c) = s$.

Proof of Proposition 4.3. Plugging the wage rule assumed in Assumption 4.6 into the general equilibrium condition (3.16) yields:

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

The proof is similar to that of Proposition 4.1, but replacing $(1 - \beta)a_t$ by $\left[\frac{1 - \beta}{1 - \beta(1 - \alpha)} \right] a_t \cdot \alpha$, defining N_t as a function of θ_t using (3.25) and (3.4), and noting that as $\theta_t \rightarrow +\infty$, $N_t \rightarrow 1$.

Appendix 4.B Graphs

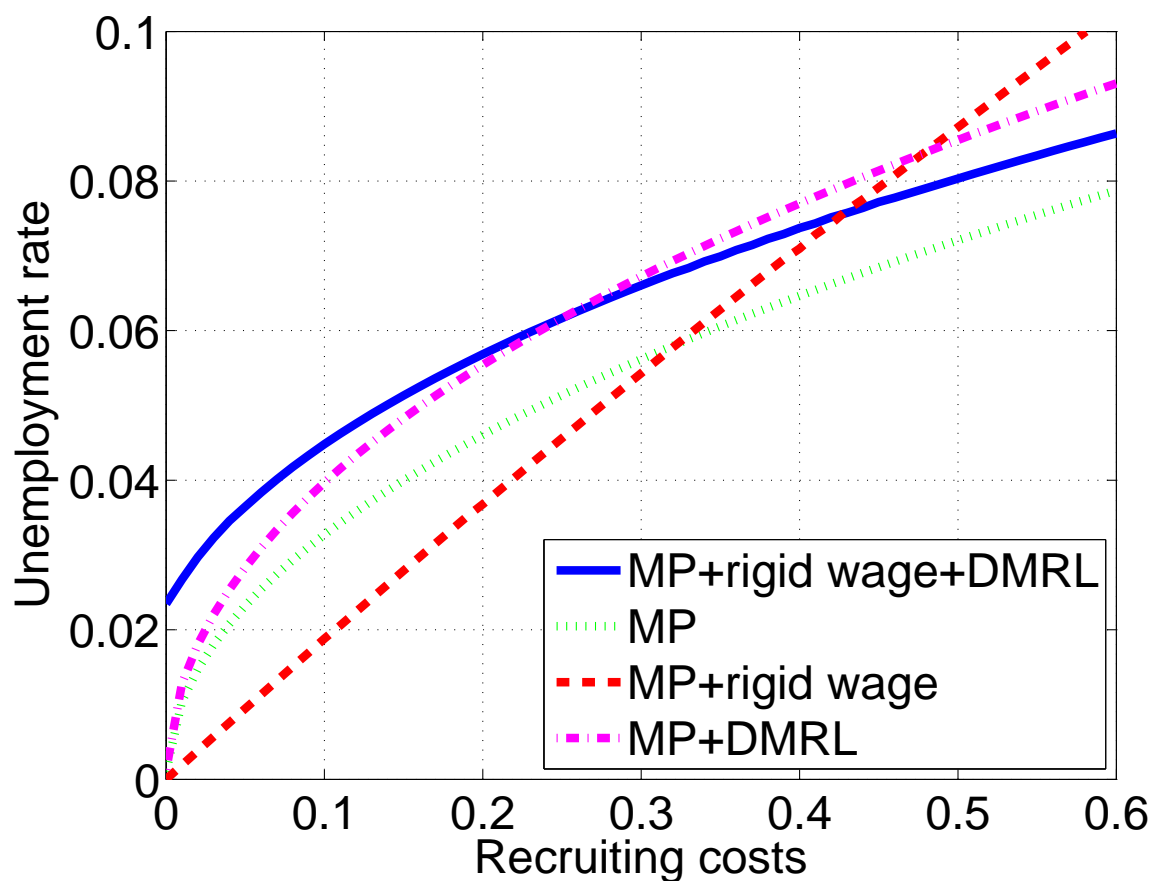


Figure 4.1: Unemployment as a function of recruiting costs across models. This graph compares the evolution of steady-state unemployment as a function of recruiting costs across various models. The MP model, MP model with rigid wages (MPS), and MP model with diminishing marginal returns to labor (SZ) and their equilibrium conditions are described in Chapter 4. These models are calibrated on Table 7.B. The MP model with rigid wages and diminishing marginal returns to labor is described in Chapter 5. This model is calibrated on Table 5.C.

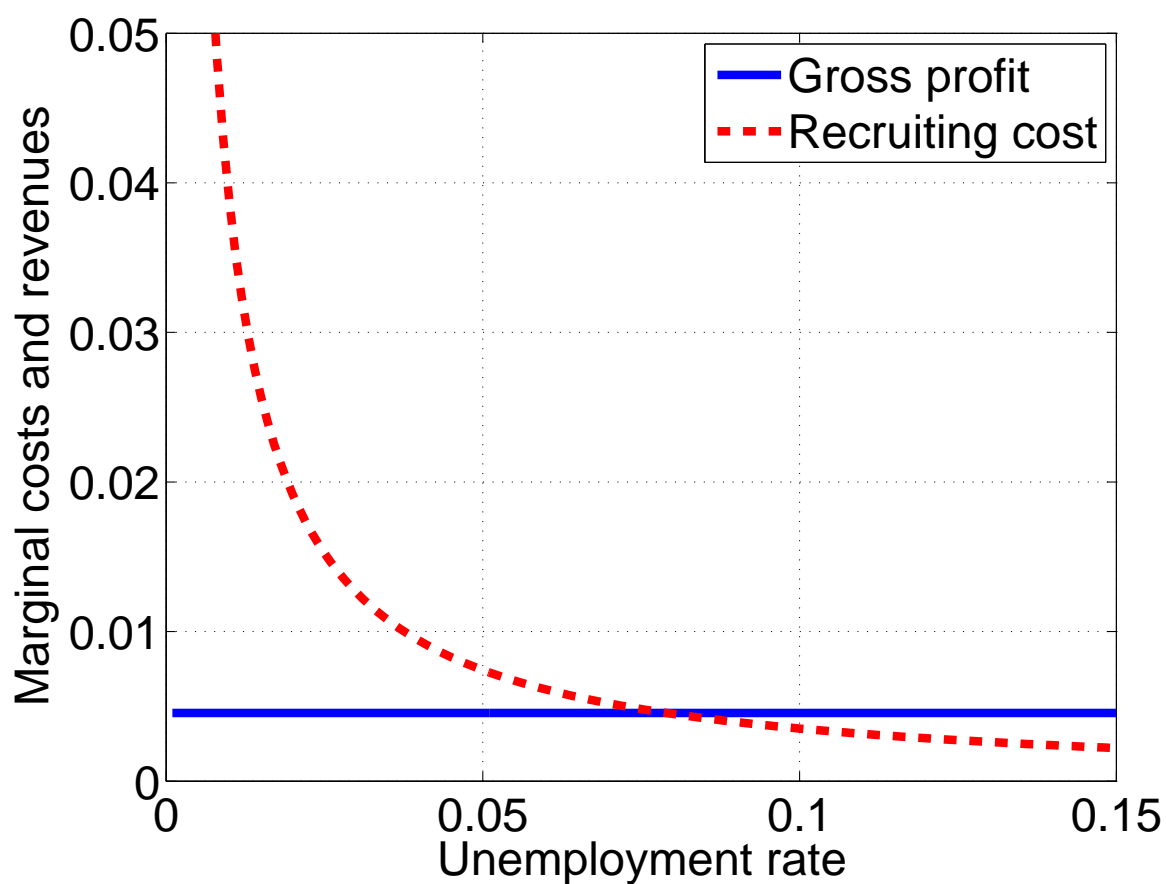


Figure 4.2: Steady-state equilibrium in the MPS model. This graph describes a steady-state equilibrium in the MPS model presented in Section 4.3. It is obtained by plotting the recruiting cost $R(\theta, c)$ and the gross marginal profit (4.2) for a continuum of unemployment rates.

Chapter 5

A Specific Model with Job Rationing

5.1 Introduction

Quantifying the fluctuations of rationing and frictional unemployment over the business cycle is necessary for assessing the economic relevance of the theory, as well as for developing policy recommendations. In this chapter, I specialize the general model presented in Chapter 3 by making functional-form assumptions on the production function and the wage schedule. We saw in Chapter 4 that neither wage rigidity nor diminishing marginal returns to labor alone suffices to introduce job rationing into the model. In this chapter, I show that job rationing arises from the combination diminishing marginal returns to labor in production and some real wage rigidity—that is, the real wage does not adjust as much as technology.

These assumptions are appealing for four reasons. First, both have been used (but not combined) in the search-and-matching literature. Second, both are empirically relevant. At business cycle frequency, some production inputs may be slow to adjust. Thus, short-run production functions are likely to exhibit diminishing marginal returns to labor. There are also substantial ethnographic and empirical literatures documenting wage rigidity. For instance, see Doeringer and Piore (1971), Blinder et al. (1998), Campbell and Kamlani (1997) and Bewley (1999) for ethnographic evidence. See Kramarz (2001) for a survey of studies based on wage microdata, as well as Dickens et al. (2007) and Elsbey (2009) for more recent evidence. Third, both assumptions are standard in the broader macroeconomic literature. There is a long tradition of macroeconomic models featuring short-run production functions with labor as the only variable input, and with diminishing marginal returns to labor (for example, Solow and Stiglitz 1968, Lindbeck and Snower 1994, Benigno and Woodford 2003). Wage rigidity features in the many general-equilibrium models that use Taylor’s (1979) and Calvo’s (1983) staggered wage-setting mechanisms—Christiano et al. (2005) and Blanchard and Galí (2007) argue that wage rigidity is important for improving realism of general-equilibrium models. Fourth, this specification of job rationing can be calibrated with readily available data. Diminishing marginal returns to labor can be estimated using aggregate

data on 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 not all workers may be employed when recruiting costs converge to zero. That is, some unemployment may remain even without recruiting costs. To understand why jobs may be rationed, and how I measure the contribution of matching frictions and job rationing to explain unemployment, let me first abstract from recruiting costs. In this case, firms hire workers until marginal revenue product of labor equals the wage. The marginal revenue product of labor decreases with employment, because the marginal product of labor decreases with employment. After a sufficiently large negative technology shocks: the marginal revenue product of labor falls; wages only partially adjust downward; such that wage may now be higher than the marginal revenue product of labor for the last workers in the labor force. These last workers will not be hired by firms, and some unemployment remains, irrespective of recruiting costs. This amount of unemployment is what I define as rationing unemployment: it measures the shortage of jobs in the economy. With positive recruiting costs, the marginal cost of labor is higher; monopolistic firms reduce production further; unemployment is higher. I define frictional unemployment as this additional unemployment, which is caused by matching frictions.

Calibrating the model and imposing technology shocks estimated in U.S. data produces moments for labor market variables that are close to their empirical counterparts. In particular, even a small amount of wage rigidity, such as that obtained by Haefke et al. (2008) using earnings of new hires, is sufficient to amplify technology shocks as much as observed in the data. In fact, the elasticity of labor market tightness with respect to technology is 15 in my model, higher than the elasticity of 9 estimated in U.S. data.¹ I also compare actual unemployment with the unemployment series simulated from actual technology. Model-generated unemployment matches actual unemployment closely. These results suggest that in spite of its simplicity, the model fits the data notably well, lending support to the quantitative analysis of unemployment and its components.

Exploiting this calibrated model, I can decompose historical U.S. unemployment into a series for rationing unemployment, and a series for frictional unemployment. These series suggest that as long as total unemployment is below 5.2%, it can all be attributed to matching frictions. In steady state, total unemployment amounts to 5.8% of the labor force, frictional unemployment to 4.3%, and rationing unemployment to 1.5%. But in the second quarter of 2009, when total unemployment reached 9.2%, rationing unemployment increased to 7.6%, while frictional unemployment decreased to 1.6%. Next, I simulate moments for unemployment and its components. I find that rationing unemployment is more than twice

¹Shimer (2005) and Costain and Reiter (2008) previously noted that Mortensen and Pissarides's (1994) model may not amplify technology shocks sufficiently, compared to empirical evidence. Mortensen and Nagypál (2007) survey the different approaches that have been used to increase amplification. Pissarides (2009) suggests that the amount of wage rigidity estimated in microdata using the wages of new hires may be insufficient to amplify shocks in a search-and-matching model.

as volatile as frictional unemployment.

Finally, the impulse response functions of unemployment and its components highlight a mechanism through which unemployment lags technology in downturns: firms intertemporally substitute recruiting from the future to the present immediately after a negative technology shock. By doing so, they take advantage of a slack labor market to recruit at low cost now, instead of recruiting in a tighter labor market in the future.

5.2 Two Assumptions

There are a variety of models with job rationing. Here, I present only one possible source of job rationing: the combination of real wages that only partially adjust to technology shocks (Assumption 5.1) with diminishing marginal returns to labor (Assumption 5.2).

ASSUMPTION 5.1 (Partially rigid wage). There exists $\gamma \in [0, 1)$ and $w_0 \in \mathbb{R}^+$ such that the wage $W_t(i)$ paid by firm i in period t is given by (3.7) where:

- (i) $S(N_t(i), a_t) = w_0 \cdot a_t^\gamma$;
- (ii) $X(\theta_t, c) = 0$;
- (iii) $Z(\theta_{t+1}, c) = 0$.

ASSUMPTION 5.2 (Diminishing marginal returns to labor). There exists $\alpha \in [0, 1)$ such that $F(N_t, a_t) = a_t \cdot N_t^\alpha$.

The introduction of wage rigidity into the model follows the reduced-form approach of the literature.² Under these assumptions, gross marginal profit becomes

$$J(N_t, a_t) = \frac{1}{M} a_t \cdot \alpha \cdot N_t^{\alpha-1} - w_0 \cdot a_t^\gamma. \quad (5.1)$$

Since $\alpha < 1$, $J(\cdot)$ decreases with employment. Since $\gamma < 1$, $J(1, a_t) < 0$ when technology a_t is low enough. Therefore, under Assumptions 5.1 and 5.2, $J(\cdot)$ satisfies Assumption 3.6. Intuitively, when the firm expands employment, the marginal product of labor falls while wages do not adjust; thus, gross marginal profit falls and is exhausted when employment is high enough. Moreover, gross marginal profit satisfies Assumption 3.7, because it increases with technology. Intuitively, when technology falls, the marginal product of labor falls

²Microfounded models of wage rigidity remain too complex to be embedded in macroeconomic models. Consequently, most macroeconomic models in the search literature use reduced-form approaches to wage rigidity. For instance, Shimer (2004), Hall (2005a), Krause and Lubik (2007), Blanchard and Galí (2008), Sveen and Weinke (2008), and Faia (2008) assume simple rigid-wage schedules. Thomas (2008) or Gertler and Trigari (2009) assume that wages can only be renegotiated at distant time intervals (Calvo (1983) wage setting).

while real wages adjust only partly to technology shocks; thus, the marginal profitability of monopolistic firms falls. Exploiting the specific functional form of the gross marginal profit, I can now repeat the analysis of Section 3.4 and propose a particular economic interpretation.

First, the interval of rationing is $\mathcal{A} = (0, a^R)$, where

$$a^R = \left(\frac{M \cdot w_0}{\alpha} \right)^{\frac{1}{1-\gamma}}. \quad (5.2)$$

The interval of rationing is wider when the markup M is higher, the steady-state wage w_0 is higher, and the production function parameter α is lower.

Second, I solve the equation $J(N, a) = 0$ with $a \in \mathcal{A}$ to find rationing unemployment:

$$U_t^R = 1 - \left(\frac{\alpha}{M \cdot w_0} \right)^{\frac{1}{1-\alpha}} \cdot a_t^{\frac{1-\gamma}{1-\alpha}}. \quad (5.3)$$

Whereas canonical search-and-matching models only highlight the role of the matching process on unemployment, this model also considers other factors. For instance, improving product market competition would reduce the markup that monopolistic firms charge, and lower rationing unemployment. Introducing these factors deepens our understanding of unemployment and suggests different ways to tackle unemployment. Frictional unemployment is implicitly determined from (3.22) and the firm's Euler equation:

$$J(N_t, a_t) = R(\theta_t, c) - (1 - s)\delta \cdot \mathbb{E}_t [R(\theta_{t+1}, c)]. \quad (5.4)$$

Finally, I specialize the results of Proposition 3.3 to this model of job rationing.

COROLLARY 5.1. *Assume that the stochastic process $\{a_t\}$ for technology follows an $AR(1)$ process and satisfies Assumption 3.11. Assume that Assumptions 3.9, 3.10, and 3.12 hold. Then sufficient conditions for the results of Proposition 3.3 to hold are*

$$1 - (1 - \alpha) \frac{\ln(1 - s)}{\ln(1 - 2.5 \cdot \sigma)} \leq \gamma \leq \frac{1}{2 - \alpha}. \quad (5.5)$$

Condition (5.5) states that for a given production function parameter α , wages need to be rigid enough to obtain sufficient fluctuations in rationing unemployment, and also need to be flexible enough to avoid layoffs with high probability. Using the calibrated parameter values derived in Section 5.4, (5.5) imposes $0.62 \leq \gamma \leq 0.79$, which is satisfied by my calibration of $\gamma = 0.7$.

5.3 Evidence

In this section, I briefly review some evidence in favors of the two central assumptions made in the previous section.

5.3.1 Diminishing marginal returns to labor

At business cycle frequency, production inputs do not adjust fully to change in employment. Capital is especially slow to adjust, and is assumed to be constant in my production function. Since my model aims to shed new light on cyclical fluctuations in unemployment, it is not concerned by long-term fluctuations in the stock of capital. In this context, assuming a short-run production function with diminishing marginal returns is reasonable.³ At longer horizon, the production function may exhibit diminishing marginal returns to labor if some production inputs such as land or managerial talent are in fixed supply.

5.3.2 Wage rigidity

I now present ethnographic evidence in support of the particular wage schedule chosen above. This wage schedule does not depend on the marginal product of labor in the firm, and does not respond to labor market conditions directly.⁴ 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 a widespread adoption of internal labor markets within firms (Jacoby 1984, James 1990). Doeringer and Piore (1971) documented that in these structures, which are motivated by concerns for equity within firms, wages are tied to job description, and are therefore insensitive to labor market and marginal productivity conditions. Galuscak et al. (2008) provide recent evidence on the major role played by internal labor markets (and not external labor markets) to explain wages paid.

Labor market institutions could also hamper downward wage adjustments, even in the face of a slack labor market. For instance, the National Industry Recovery Act of 1933 is often blamed for persistent high real wages during the Great Depression (Temin 1990, Cole and Ohanian 2004). More recently, unions adamantly opposed nominal pay cuts during the Finnish Depression of 1991-1993, in spite of rampant unemployment (Gorodnichenko et al. 2009).

Lastly, managerial best practices oppose pay cuts. Detailed interviews of compensation managers by Bewley (1999) provide evidence that employers avoid pay cuts even in bad

³Elsby and Michaels (2008) make this argument as well.

⁴If a firm decides to increase employment, marginal product of labor falls but wages remain constant. If labor market conditions change independently of technology (e.g., if separation rate or recruiting costs vary), wages remain constant.

times because they believe pay cuts antagonize workers and ultimately reduce productivity and profitability. Bewley’s findings are confirmed by surveys of human resource officers across countries and industries (Kaufman 1984, Blinder and Choi 1990, Agell and Lundborg 1995, Agell and Lundborg 1999, Campbell and Kamlani 1997), and by the study of workers’ reactions to pay cuts in natural experiments (Krueger and Mas 2004, Mas 2006).

As I have just argued, various reasons could explain diminishing marginal returns to labor and wage rigidity. To discipline the empirical exercise, I now calibrate the wage schedule and production function to be consistent with empirical evidence on wage dynamics and the labor share, respectively.

5.4 Calibration

The model developed in Section 5.2 provides an intuitive understanding of unemployment and its components, and yields analytical results. This tractability and portability come at the cost of realism. Therefore, I follow the tradition of Kydland and Prescott (1982) and calibrate the model using micro and macro evidence. I calibrate all parameters at a weekly frequency, which is a good approximation for the continuous-time nature of unemployment flows.⁵ Table 5.C summarizes the calibrated parameters.

5.4.1 Stochastic process for technology

I estimate the log of technology as a residual $\log(a_t) = \log(Y_t) - \alpha \cdot \log(N_t)$. This measure of technology corresponds more closely to the concept of technology defined in the model—in which there is no capital—and is commonly used in the literature (for example, Shimer 2005, Gertler and Trigari 2009). Y_t and N_t are seasonally-adjusted, quarterly real output and employment in the nonfarm business sector, respectively, and are constructed by the BLS Major Sector Productivity and Costs (MSPC) program. The sample period is 1964:Q1–2009:Q2. To emphasize business-cycle-frequency fluctuations, I take the difference between log technology and a low frequency trend—a Hodrick-Prescott (HP) filter with a smoothing parameter 10^5 , as in Shimer (2005). I estimate the stochastic process followed by detrended log technology as an AR(1) process with mean zero: $\log(a_{t+1}) = \rho \log(a_t) + z_{t+1}$, where $z \sim N(0, \sigma^2)$. I obtain an autocorrelation of 0.897 and a conditional standard deviation of

⁵I consider a week as 1/12 of a quarter and 1/4 of a month. The relevant measure of unemployment in the model is beginning-of-period unemployment, which determines labor market tightness and recruiting costs. As discussed in Section 3.4.3, part of beginning-of-period frictional unemployment comes mechanically from the discrete inflow of labor into unemployment at the end of each period, caused by job destructions. This component of frictional unemployment is an artifact of the discrete-time structure of the model, which can be minimized by calibrating the model at weekly frequency. Models are commonly calibrated at such frequency in the literature (for example, Hagedorn and Manovskii 2008, Elsby and Michaels 2008).

0.0087. At weekly frequency, this requires setting $\rho = 0.991$ and $\sigma = 0.0026$.⁶

5.4.2 Preferences

I calibrate the markup at $M = 1.11$, using Christiano et al.'s (2005) estimation of a general-equilibrium model with flexible prices. This markup corresponds to an elasticity of substitution across goods of $\epsilon = 9$.

5.4.3 Labor market

I first estimate the recruiting cost as a fraction of the wage bill (c), the job destruction rate (s), and the matching function (ω, η). To estimate the separation rate s , I use the seasonally-adjusted, monthly time series for Total Separations in all nonfarm industries, computed by the Bureau of Labor Statistics (BLS) from the Job Openings and Labor Turnover Survey (JOLTS) for the period from December 2000 to June 2009.⁷ The average separation rate is 0.038. At weekly frequency, the separation rate is 0.0095.

For the recruiting cost, I use the microeconomic evidence 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.⁸ These numbers account only for the labor costs of recruiting. Silva and Toledo (2006) argue that recruiting could also involve advertising, agency fees or even travel costs for applicants. Using data collected by PricewaterhouseCooper, they report that 0.42 of a worker's monthly wage could be spent on each hire. Unfortunately, they do not report recruiting times. Using the average job-filling rate of 1.3 in JOLTS, 2000–2009, the flow cost of recruiting would be 0.54 of a worker's wage, which seems large as it amounts to five times the labor costs reported by Barron et al. (1997). I calibrate flow recruiting costs as 0.32 of a worker's wage, the midpoint between the two previous estimates.⁹

⁶Non-detrended data are more persistent. When I repeat the estimation with non-detrended quarterly technology, I obtain an autocorrelation of 1.0043 and a conditional standard deviation of 0.0090.

⁷December 2000 to June 2009 is longest period for which time series from JOLTS are available. Comparable data were unfortunately not available before December 2000.

⁸Using the 1980 Employment Opportunity Pilot Project survey (2,994 observations) they find that employers spend on average 5.7 hours per offer, make 1.02 offers per hired worker, and that it takes employers 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 (2006)), the flow cost of keeping an open vacancy is $c = 0.071$ 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 $c = 0.106$. Finally, 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 $c = 0.117$.

⁹Using the average unemployment rate and labor market tightness in JOLTS, I find that $c = 0.32$ corresponds to 0.89% of the total wage bill being spent on recruiting. My estimate is average compared to others found in the literature: for example, 0.213 in Shimer (2005), 0.357 in Pissarides (2009), or 0.433 in

Following the literature (for example, Hall 2005a), I specify the matching function as

$$h(U, V) = \omega U^\eta V^{1-\eta}, \quad (5.6)$$

and pick $\eta = 0.5$, which is reasonable in light of empirical results surveyed by Petrongolo and Pissarides (2001). To estimate the matching efficiency ω , I use seasonally-adjusted, monthly series for the number of hires and vacancies from JOLTS, 2000–2009. I use the seasonally-adjusted, monthly unemployment level computed by the BLS from the Current Population Survey (CPS) over the same 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. I compute the least-squares estimate of ω , which minimizes $\sum_i (f_i - \omega \theta_i^{1-\eta})^2$:

$$\hat{\omega} = \frac{\sum_i \theta_i^{1-\eta} f_i}{\sum_i \theta_i^{2(1-\eta)}}.$$

The resulting estimate is $\hat{\omega} = 0.93$. My estimate at weekly frequency is therefore 0.23.

Finally, I calibrate the wage w_0 to obtain a steady-state unemployment of 5.8%, which is the average of a low frequency trend—an HP filter with smoothing parameter 10^5 —for unemployment over the period 1964–2009.¹⁰

5.4.4 Estimates of diminishing marginal returns to labor

In steady-state, the labor share $\bar{l}s \equiv (\bar{w} \cdot \bar{n}) / \bar{y}$ is:

$$\bar{l}s = \frac{\alpha}{M} - [1 - \delta(1 - s)] \cdot \frac{c}{q(\bar{\theta})} \cdot \bar{n}^{1-\alpha}.$$

I target a steady-state labor share of $\bar{l}s = 0.66$ and a steady-state unemployment rate of $\bar{u} = 5.8\%$. Using the calibration of the labor market above, these targets imply steady-state employment $\bar{n} = 0.951$, and steady-state labor market tightness $\bar{\theta} = 0.45$.¹¹ Finally, I estimate the production function parameter α at 0.74, which is larger than the labor share because of monopolistic rents and recruiting costs.

5.4.5 Estimates of wage rigidity

Estimate from aggregate wage data. Table 5.C estimates the elasticity of aggregate wages with respect to technology. I use average real hourly earning in the nonfarm business

Hall and Milgrom (2008).

¹⁰The unemployment series used is a quarterly average of monthly unemployment rates constructed by the BLS. The average unemployment rate over the same period is nearly identical, at 5.9%.

¹¹Refer to Appendix 5.B for a complete description of the steady-state of the general-equilibrium model.

sector as the wage series. I estimate $\gamma = 0.44$ ($s.e. = 0.07$), in line with previous studies (for example, Hagedorn and Manovskii 2008).¹²

I also perform robustness checks, as detailed in Table 5.C, which confirm that aggregate wage data exhibit mild procyclicality. In particular, I use as wage series the measure of total compensation in private industries constructed by the BLS as part of the Employment Cost Index (ECI).¹³ This index measures change in the cost of labor, controlling for employment shifts among occupations and industries over the business cycle. Thus, this wage measure is not prone to the composition bias previously exhibited in other aggregate wage data by Solon et al. (1994). I find $\gamma = 0.28$ ($s.e. = 0.10$). This estimate does not suggest a stronger procyclicality of wages once composition bias is controlled for.

Microevidence. I now present estimates of wage rigidity obtained in the literature using microdata on workers' individual wages. Panel data on individual workers usually show more cyclicity than aggregate data because they are less prone to composition effects. Surveying studies such as Bils (1985), Solon et al. (1994), or Shin and Solon (2008), Pissarides (2009) estimates the technology-elasticity of wages for job stayers in the 0.3–0.5 range for the U.S.¹⁴

However, Pissarides (2009) argues that wages of job movers may actually be more cyclical. The task of estimating wage rigidity for newly hires is arduous. As noted by Gertler and Trigari (2009), there are obvious composition effects among jobs newly created over the business cycle, which are difficult to control for. For instance, it is possible that workers hired in recessions and booms differ, and that the types of jobs created and destroyed differ as well. In particular, workers may accept lower-paid jobs in recessions (“stopgap jobs”), and move to better jobs during expansions. Martins et al. (2009) are one of the first studies to estimate wage flexibility for new hires, controlling for these composition effects. They use Portuguese employer-employee longitudinal data over the period 1982–2007.¹⁵ Surprisingly, their estimates of wage cyclicity for job movers in line with those of Solon et al. (1994) for all job stayers in the U.S.—an unemployment-elasticity of -1.5, which corresponds to a

¹²The wage series is seasonally-adjusted, average hourly earning in the nonfarm business sector, constructed by the BLS Current Employment Statistics (CES) program. It is deflated by the seasonally-adjusted Consumer Price Index (CPI) for all urban households constructed by BLS. Average hourly earning is a quarterly series, and CPI is a quarterly average of monthly series. The quarterly technology series used is the one presented in Section 5.4.1. Wage and technology series are detrended using an HP filter with smoothing parameter 10^5 . The sample period is 1964:Q1–2009:Q2.

¹³Compensation of private industry workers is a seasonally-adjusted, quarterly series that I deflate using the CPI. The quarterly technology series used is that presented in Section 5.4.1. Wage and technology series are detrended using an HP filter with smoothing parameter 10^5 . The sample period used is 2001:Q1–2009:Q2

¹⁴The studies surveyed by estimate unemployment-elasticities. Therefore, Pissarides (2009) estimates a relationship between technology and unemployment. He then multiplies unemployment-elasticities by -0.34 to convert them to technology-elasticities.

¹⁵The authors argue that their results are not driven by specificities of the Portuguese labor market, since wages tend to exhibit more cyclicity in Portugal than in the U.S.

technology-elasticity of around 0.5. This suggests that the cyclical of entry wages may not be higher than that of wages paid to continuing workers.

A recent study by Haefke et al. (2008) estimates the technology-elasticity of job movers using panel data for U.S. workers. They do not control for composition bias in the type of jobs accepted by workers over the cycle because of data limitations. As expected, their estimate is higher than that of Martins et al. (2009). 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 use an elasticity of $\gamma = 0.7$ in my calibration, and show in Section 5.6 that this estimate suffices to deliver large fluctuations in total and rationing unemployment over the business cycle.¹⁶

5.5 Empirical Properties of the Model

Having calibrated the model with matching frictions and job rationing, I now study the quantitative properties of rationing and frictional unemployment in this model.

5.5.1 Beveridge Curve

To provide some intuition, I represent steady-state total, rationing, and frictional unemployment as functions of labor market tightness. These curves in the (θ, u) plane are Beveridge curves, and shifts in technology induce movements along these curves.

Figure 3.1 depicts the standard Beveridge curve (solid line), which relates total unemployment to labor market tightness, and its decomposition into curves for frictional (dotted line) and rationing (dashed line) unemployment. When total unemployment rises above 5%, which corresponds to a labor market tightness below 0.6, some rationing unemployment prevails. In this case, technology a is in the interval of rationing $\mathcal{A} = (0, a^R)$. As technology falls further, labor market tightness falls and rationing unemployment increases. When labor market tightness is above 0.6, jobs are not rationed ($a \geq a^R$), and all unemployment is frictional. In this regime, frictional unemployment increases as labor market tightness decreases. When labor market tightness falls below 0.6, jobs are rationed ($a < a^R$) and frictional unemployment decreases as labor market tightness decreases. It is clear that

¹⁶The elasticity estimated by Haefke et al. (2008) (0.7) is with respect to labor productivity $\log(y) - \log(n)$. For my calibration, I should use the elasticity with respect to technology $\log(y) - \alpha \cdot \log(n)$. Labor productivity is slightly less procyclical and less volatile than technology, so I should calibrate the model with an elasticity slightly lower than 0.7. Accordingly, my quantitative results underestimate slightly the amount of fluctuations in unemployment and its components, and overestimate slightly the amount of fluctuations in wages. The difference in the volatility of these two measures of productivity is minor: the unconditional standard deviation of log technology in the U.S. for the 1964–2009 period is 0.0196, against an unconditional standard deviation of 0.0180 for log labor productivity. Thus, log labor productivity only is 8% less volatile than log technology.

steady-state frictional unemployment is bounded above and reaches its maximum for $a = a^R$. With my calibration, it never rises above 5%.

5.5.2 Impulse response functions in log-linearized model

To understand how labor market variables respond to a technology shock, I compute impulse response functions (IRFs) in a log-linearized model.¹⁷ I perturb the log-linearized model with an adverse shock to technology of one standard deviation (-0.0026). The IRFs are shown in Figure 5.1. On impact, output, consumption, employment, labor market tightness, the number of hires, and wages fall discretely.

The drop in labor market tightness is about 15 times the drop in technology. This implies an elasticity of labor market tightness with respect to technology of 15. The empirical counterpart of this elasticity is the coefficient obtained in an OLS regression of log labor market tightness on log technology. This coefficient can be derived from Table 5.C that presents moments in U.S. data for the period 1964–2009: $\rho(\theta, a) \times \sigma(\theta)/\sigma(a) = 0.479 \times 0.344/0.019 = 8.67$. The simulated elasticity is higher than its empirical counterpart. Therefore, a small amount of wage rigidity (as observed in microdata for new hires) is more than sufficient to generate fluctuations in labor market tightness in response to technology shocks of a magnitude observed in the data.¹⁸ In the next section, I simulate my model to detail how unemployment and vacancies contribute to the fluctuations in the ratio of vacancies to unemployment, which is my measure of labor market tightness.

This result contributes to a large literature on the role of wage rigidity in explaining unemployment fluctuations and confirms a comparative-static exercise presented in Hall and Milgrom (2008). Following Shimer's (2005) critique of the standard search-and-matching model, several studies used variants of the standard model involving higher wage rigidity to generate greater fluctuations in unemployment: for instance, Hall (2005a) studies the effect of real wage rigidity; Hall and Milgrom (2008) propose a different bargaining mechanism that delivers more rigid wages; and Gertler and Trigari (2009) introduce staggered real-wage setting. This line of research has been criticized for exaggerating the rigidity of wages in spite of empirical evidence suggesting that wages for new hires are more flexible than that of existing workers (for example, Pissarides 2009, Haefke et al. 2008). Calibrating my model with an estimate of wage cyclicalities from microdata of new hires, I show that even a small amount of rigidity is sufficient to amplify technology shocks as much as in the data.

¹⁷For further details on the log-linearization, please see Appendix 5.B.

¹⁸If labor hoarding plays an important role in reality, then measured fluctuations in technology are partly due to true fluctuations in technology, and partly due to fluctuations in labor utilization. Therefore, actual fluctuations in technology are smaller than measured fluctuations in technology, and the true elasticity of labor market tightness with respect to technology is higher than the estimated elasticity of 8.7. However, the empirical validity of the model is not at stake because the elasticity of labor market tightness with respect to technology in the model is quite higher than 8.7, and is around 15.

Since there are no endogenous separations, unemployment behaves as a state variable, and it does not jump on impact. Instead, it slowly builds, peaking around 4 months after the technology shock. This result is in line with the empirical findings of Stock and Watson (1999), which suggest that employment lags the business cycle by approximately one quarter in the U.S., whereas technology slightly leads the cycle.

Finally, Figure 5.2 shows how rationing and frictional unemployment respond to a negative technology shock. Rationing unemployment jumps up on impact. Frictional unemployment, on the other hand, jumps down. This simulation result confirms the theoretical results derived in Section 3.4: when technology is in the interval of rationing, which is the case at steady state, and an adverse technology shock hits the economy, total and rationing unemployment rise, while frictional unemployment falls.

5.5.3 Simulated moments

Before delving further into a quantitative analysis of unemployment and its components, I verify that the model provides a sensible description of reality by comparing important simulated first and second moments to their empirical counterparts. A comparison of simulated and empirical moments suggests that in spite of its simplicity, this model performs well at replicating labor market fluctuations.

First moments. The average unemployment rate for the period 2000–2009 is $\bar{u} = 5.3\%$. Using estimates of the job destruction rate and matching function, as well as equation (5.8) that relates steady-state unemployment and labor market tightness, I infer that steady-state labor market tightness $\bar{\theta} = 0.54$. Its empirical counterpart is the average labor market tightness from JOLTS over the period 2000–2009, which is the average ratio of number of vacancies to number of unemployed. I find that average labor market tightness is 0.58: the similarity of these two values suggests that the matching paradigm, together with my calibration, describes mechanics of the labor market well.

Second moments. I now 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 . The moments in U.S. data during 1964–2009 are presented in Table 5.C. Unemployment U is a quarterly average of the monthly unemployment series constructed by the BLS. Output Y is real output in the nonfarm business sector. Technology a is constructed in Section 5.4.1. The quarterly real wage series is average hourly wage in nonfarm business sector. To construct a series of vacancies over the period, I merge the job openings data from JOLTS for 2001–2009, with the Conference Board help-wanted advertising index, measured as the number of help-wanted advertisements in major newspapers, for 1964–2001. This dataset is a standard proxy for vacancies (for example, Shimer 2005). JOLTS began only in December 2000, and the Conference Board data become less relevant after 2000 due to the major role taken by the

Internet as a source of job advertising, which made the merger of both datasets necessary. I construct labor market tightness θ as the ratio of vacancies to unemployment, constructed by the BLS from CPS. All variables are seasonally-adjusted and expressed in logs as deviations from trend obtained by applying an HP filter with smoothing parameter 10^5 to the quarterly data.

I generate a series of technology shock (z_t) with $z_t \sim N(0, 0.0026)$ for all t , with which I perturb the log-linearized system. I obtain weekly series of log-deviations for all the variables. I then record values every 12 weeks for the series (Y_t), (a_t), and (W_t), which have quarterly frequency in the data. I record values every 4 weeks and then take quarterly averages for the series (U_t), (V_t), and (θ_t), which have monthly frequency and are averaged to quarterly series in the data. I discard the first 1,200 weeks of simulation to remove the effect of initial conditions. I have simulated a total of 200 samples of 182 quarters (2,184 weeks), corresponding to quarterly data from 1964:Q1 to 2009:Q2. Each sample gives me an estimate of the means of the model-generated data. I compute standard deviations of estimated means across model-generated samples, which indicate the precision of model predictions. Simulated moments are presented in Table 5.C.

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. For unemployment, vacancies, and labor market tightness, simulated standard deviations are close, but lower than empirical moments. Simultaneously, simulated correlation of these variables with technology is close to 1, but empirical correlations are below 0.5. This implies that in the data, fluctuations in labor market variables are driven in part by technology, and in part by other shocks. Because my simple model only considers technology shocks, it cannot achieve the degree of volatility observed in the data. However, as seen with IRFs, amplification is at least as strong as in the data. The simulated correlation of unemployment with vacancies is -0.92, very close to the empirical value of -0.89.

The moments of unemployment U , vacancies V help better understand where fluctuations in labor market tightness θ come from. In my model, Table 5.C shows that a 1% decrease in technology increases unemployment by 6.9% and reduces vacancies by 8.2%, therefore reducing the vacancy-unemployment ratio (my measure of labor market tightness) by 15.1%. In U.S. data summarized in Table 5.C, I estimate that a 1% decrease in technology increases unemployment by 4.2% and reduces vacancies by 4.3%, therefore reducing the vacancy-unemployment ratio by 8.5%. Therefore, both vacancies and unemployment respond sufficiently to technology shocks in my model.

The behavior of output is similar in the model and the data. But aggregate wages vary twice as much in the data as in the model. Nominal factors are one source of discrepancy.¹⁹ In

¹⁹The correlation of wages to technology is only 0.646 in the data. Wages have been documented to exhibit a significant amount of nominal rigidity (for example, Akerlof et al. 1996). Adding log price level as a regressor in a regression of log wage on log technology increases the R^2 from 0.19 to 0.65. My preferred estimate for the coefficient on price is around -0.35 (s.e.=0.03). The coefficient on technology falls to 0.30

addition, wage and unemployment are too closely correlated in the model, because rigid wages are the only channel through which technology shocks lead to unemployment fluctuations. In reality, other shocks and channels are at play.

5.5.4 Robustness checks

IRFs in the nonlinear model. I use Fair and Taylor's (1983) shooting algorithm with perfect foresight to compute exact impulse response functions (IRFs) to large negative technology shocks in the exact nonlinear model. Figure 5.9 displays the responses of labor market tightness, total, rationing, and frictional unemployment. The first observation from these exact IRFs is that after a negative technology shock, rationing unemployment rises while frictional unemployment decreases, consistent with the IRFs in the log-linearized model.

The second observation from the decomposition of unemployment is a mechanism through which unemployment lags technology in downturns. For large adverse shocks, frictional unemployment may even become negative on impact. When frictional unemployment becomes negative, matching frictions actually reduce unemployment. In the periods immediately following a drop in technology, firms intertemporally substitute recruiting from future periods to the present. Firms take advantage of a slack labor market to recruit at low cost now, instead of recruiting in a tighter labor market in the future. These intertemporal substitution effects caused by matching frictions slows the growth of unemployment in the short run, and delay the spike of unemployment by about a quarter.

No-inefficient-separation condition. When I compute the responses shown in Figure 5.9 with the shooting algorithm, I allow firms to lay workers off if it is profitable to do so. Labor market tightness, however, always remains positive; therefore, it is never optimal for firms to lay workers off under the calibrated wage schedule, even after very large technology shocks.

5.6 Quantitative Characterization of Unemployment Components

5.6.1 Actual and model-generated unemployment

This section compares model-generated unemployment with U.S. post-war unemployment. For this analysis, I cannot use a log-linearized model because rationing and frictional unemployment are nonlinear. When the economy departs from steady-state, rationing unemployment falls to zero in booms; frictional unemployment is increasing with technology in

(s.e.=0.06).

the interval of rationing, but is decreasing outside it; this makes the log-linear model a poor approximation for this exercise. Instead I use the nonlinear model.

First, I approximate the AR(1) stochastic process for technology estimated in Section 5.4 as a 200-state Markov chain (Tauchen 1986, Tauchen and Hussey 1991). I detrend the technology series constructed in Section 5.4.1 from U.S. data, using an HP filter with smoothing parameter 10^5 . I discretize detrended technology in the state space of the Markov chain for technology. This discretization yields a series of state realizations that I use to stimulate the model.

Second, I assume that flows into and out of employment balance each other (Assumption 3.9). This assumption, together with the assumption that technology shocks follow a Markov process, allow me to express implicitly equilibrium labor market tightness, employment, and unemployment as a function of technology. Then solving the nonlinear, rational-expectation model boils down to solving a system of nonlinear equations with as many equations as states of technology, which can easily be done numerically.

Third, since each state of technology is associated with a given unemployment rate, I can associate each observation of quarterly technology in U.S. data with a model-generated unemployment rate. Comparing simulated and actual unemployment indicates how much of unemployment fluctuations can be explained by the model.²⁰ The two series are shown on the top graph in Figure 5.3. Both have the same standard deviation of 0.010. While not perfect, the match is remarkably good given the simplicity of the model: the correlation of the two series is 0.55 and even higher on the first half of the sample.

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 5.3. The fit of the model remains good.

5.6.2 Historical decomposition of unemployment

The preceding sections suggest that the model matches empirical data quite well. I can now examine how the model decomposes U.S. post-war unemployment into rationing and frictional components. I pursue the exercise from Section 5.6.1, and associate each observation of quarterly technology in U.S. data with model-generated rationing and frictional unemployment rates computed with (5.3) and (5.4). Figure 5.5 shows the resulting decomposition of model-generated unemployment. In this framework, unemployment is solely frictional below 5.2%. Above 5.2%, there is some rationing and some frictional unemployment. Moreover, it is clear that frictional unemployment falls when rationing unemployment rises. Indeed,

²⁰More precisely, I detrend quarterly unemployment using an HP filter with smoothing parameter 10^5 , in order to make it comparable to simulated unemployment obtained with a HP-filtered technology series.

spikes in unemployment are accompanied by sharp drops in frictional unemployment, and steep rises in rationing unemployment. Based on the actual technology series for the U.S., the model predicts that unemployment should have been highest in the 1981–1982 recession. It predicts that unemployment should have peaked at 9.2%, with frictional unemployment falling to 1.6% of the labor force, and rationing unemployment reaching 7.6%. However, actual (detrended) unemployment only reached 8.5% during this recession. On the other hand, the model underestimates unemployment in the current recession: unemployment reached 9.2% (as of 2009:Q2), but the model only predicts a peak of unemployment at 8.5%, with frictional unemployment at 2.3% and rationing at 6.2%. These discrepancies suggest that factors other than technology drove unemployment fluctuations during these periods.

I repeat the decomposition exercise using utilization-adjusted TFP series from Fernald (2009) as the driving force in the model. Unlike the technology series used so far, this TFP series accounts for labor hoarding and variable capital utilization. The decomposition is presented on Figure 5.6 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.

Finally, I approach the decomposition exercise from another angle. I determine the technology series such that model-generated unemployment matches actual unemployment exactly. Then, I infer rationing and frictional unemployment rates from this technology series.²¹ The decomposition is shown on Figure 5.7. Current events illustrate how the composition of unemployment drastically changes over the business cycle. In 2007:Q2, actual unemployment was at 4.9%, all of which was frictional. In 2008:Q2, actual unemployment was at 5.8%, of which 4.3% was frictional unemployment and 1.5% was rationing unemployment. Finally, in 2009:Q2, actual unemployment reached 9.2%, frictional unemployment fell to 1.6%, and rationing unemployment increased drastically to 7.6%.

5.6.3 Simulated moments

Table 5.C reports the moments of unemployment and its components obtained by simulating the calibrated model. I use the same framework as in the two previous sections (Sections 5.6.1 and 5.6.2). I simulate a weekly series of technology using the Markov-chain approximation described in Section 5.6.1. I obtain a weekly series for all the variables in the model. I record values every 12 weeks to obtain quarterly series for all variables. I discard the first 1,200 weeks of simulation in order to remove the effect of initial conditions. I have simulated a total of 200 samples of 182 quarters, corresponding to quarterly data from 1964:Q1 to 2009:Q2. I compute means of the model-generated data, and standard deviations of estimated means

²¹This 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 (see Section 5.6.1). This limitation notwithstanding, the exercise provides another useful illustration of the theoretical results of the paper.

across model-generated samples.

On average, frictional unemployment is about twice as high as rationing unemployment (3.9% versus 2.0%). But rationing unemployment is more than twice as volatile as frictional unemployment; quarterly standard deviations are 0.021 and 0.008 respectively. Rationing unemployment is also nearly twice as volatile as total unemployment, whose quarterly standard deviation is 0.013.

5.7 Concluding Remarks

This chapter specifies a model in which job rationing arises, in an equilibrium framework, from real wage rigidity and diminishing marginal returns to labor. I calibrate and evaluate this model, to find that the model describes fluctuations of labor market variables well. I will show in Chapter 7 that under this natural calibration, the model seems to perform better than existing models of comparable complexity. The good fit of the model is an important result, as we need a working model of unemployment over the business cycle to be able to (i) conduct theoretical and empirical research on unemployment, and (ii) guide policymakers as they design labor market policies to alleviate the problem of unemployment.

Furthermore, the empirical validity of the model allows me to pursue the quantitative work further. I decompose U.S. unemployment for the postwar period to construct historical time series for rationing unemployment and frictional unemployment. These time series suggest that the fluctuations in the composition of unemployment are quantitatively large.

These quantitative results about the fluctuations of unemployment components have novel and important policy implications. The reason is that the government does not fight job rationing and matching frictions with the same policy instruments. So realizing that there is a large component of unemployment due to job rationing changes the policy recommendations compared to search-and-matching model. In particular, it is obvious that policies should be directed to improving matching in good times, and creating jobs in bad times. I study this issue further in Chapter 6.

One of the keystone of the results derived in this Chapter is the property that it becomes cheaper for firms to recruit in bad times. This property derives from a standard calibration of matching function borrow from Powers and Powers (2001), which implies that the job-filling probability $q(\theta)$ decreases with θ , and that the expected recruiting cost per hire $c/q(\theta)$ increases with θ . In this context, a first question arise: Is there more direct evidence that it is actually easier to recruit when the labor market becomes slacker and unemployment increase? Figure 5.10, which plots the estimated job-filling probability as a function of the unemployment rate in the U.S. for the 2001–2009 period, is very clear evidence that it becomes easier to recruit in bad times. It shows that when unemployment is higher, the rate at which firms fill vacancies is higher. Even though firms may receive a higher number of applications from a more diverse pool of applicants in bad times, higher unemployment

makes recruiting easier for firms.

A second question that should be addressed is that of the definition of vacancies. Posting vacancies adds to the cost of recruiting, but a more significant part of recruiting costs is probably due to resources spent on screening applications and interviewing applicants. Therefore, it is important to determine whether these elements of the recruiting process are included in the definition of a vacancy; it turns out that they are. The Job Openings and Labor Turnover Survey (JOLTS) provides the empirical definition of a vacancy: “A job opening requires that 1) a specific position exists, 2) work could start within 30 days, and 3) the employer is actively recruiting from outside of the establishment to fill the position. Included are full-time, part-time, permanent, temporary, and short-term openings. Active recruiting means that the establishment is engaged in current efforts to fill the opening, such as advertising in newspapers or on the Internet, posting help-wanted signs, accepting applications, or using similar methods.” Hence, the JOLTS definition of a vacancy includes screening, interviewing, and other recruiting efforts. This implies that in bad times, a large share of the recruiting process becomes faster, and a large share of the total recruiting costs shrinks.

Appendix 5.A Proofs

Proof of Corollary 5.1. I need to determine a sufficient condition for Assumption 3.8. Using (5.1):

$$J(N^R(a) - n, a) = \frac{\alpha}{M} a \cdot [N^R(a) - n]^{\alpha-1} - w_0 \cdot a^\gamma$$

$$\nabla_n J(N^R(a) - n, a) = \frac{\alpha \cdot (1 - \alpha)}{M} \cdot [a^{1/(\alpha-2)} \cdot N^R(a) - a^{1/(\alpha-2)} \cdot n]^{\alpha-2}.$$

Since $(2 - \alpha) \geq 0$ and $N^R(a) - n \forall n \in [0, N^R(a)] \geq 0$, part (ii) holds if and only if

$$\nabla_a [a^{1/(\alpha-2)} \cdot N^R(a) - a^{1/(\alpha-2)} \cdot n] \geq 0.$$

A sufficient condition is

$$\nabla_a [a^{1/(\alpha-2)} \cdot N^R(a)] \geq 0,$$

because $-\nabla_a [a^{1/(\alpha-2)} \cdot n] \geq 0$. Since

$$a^{1/(\alpha-2)} \cdot N^R(a) = \left(\frac{\alpha}{M \cdot w_0} \right)^{\frac{1}{1-\alpha}} \cdot a^{\frac{1-\gamma}{1-\alpha} - \frac{1}{2-\alpha}},$$

a sufficient condition is

$$\frac{1-\gamma}{1-\alpha} - \frac{1}{2-\alpha} \geq 0,$$

which implies $\gamma \leq \frac{1}{2-\alpha}$. Next, 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. Assume that no such layoffs occurred at time t . Using the approximation developed in the proof of Proposition 3.3, the equilibrium condition becomes:

$$\frac{\alpha}{M} a_t N_t^{\alpha-1} - w_0 a_t^\gamma = (1 - \delta(1-s))R(\theta_t, c) - \sigma^2 \nabla_\theta^2 R \cdot (\nabla_a \theta)^2.$$

Notice that $\nabla_\theta^2 R < 0$, so that I can infer:

$$N_t^{\alpha-1} \geq \frac{M w_0}{\alpha} a_t^{\gamma-1}. \quad (5.7)$$

A necessary and sufficient condition to avoid endogenous layoffs in period $t+1$ is:

$$\frac{\alpha}{M} a_t (1-s)^{\alpha-1} N_t^{\alpha-1} - w_0 a_t^\gamma + \mathbb{E}_{t+1} [R(\theta_{t+2}, c)] \geq 0.$$

Since $R \geq 0$, a sufficient condition is

$$\frac{\alpha}{M} a_t (1-s)^{\alpha-1} N_t^{\alpha-1} - w_0 a_t^\gamma \geq 0.$$

From (5.7), and using $a_{t+1} = a_t + z_t$, I find a sufficient condition on the technology shock in period t :

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

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:

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

Since $a_t \geq 0.93$ in practice (for instance once I discretize the AR(1) process using a 200-state Markov chain), imposing $\left[1 - (1-s)^{\frac{1-\alpha}{1-\gamma}} \right] > 2.5 \cdot \sigma$ ensures that endogenous layoffs occur with probability below 1%.

Appendix 5.B Complete Log-Linear 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 $\{\bar{c}, \bar{n}, \bar{y}, \bar{h}, \bar{\theta}, \bar{u}, \bar{w}\}$ is characterized by the following equations:

$$\bar{u} = \frac{s}{s + (1-s)f(\bar{\theta})} \quad (5.8)$$

$$\bar{n} = \frac{1-\bar{u}}{1-s} \quad (5.9)$$

$$\bar{h} = s \cdot \bar{n} \quad (5.10)$$

$$\bar{c} = \bar{n}^\alpha - \frac{c \cdot s}{q(\bar{\theta})} \bar{n} \quad (5.11)$$

$$\bar{y} = \bar{n}^\alpha \quad (5.12)$$

$$\bar{w} = w_0 \quad (5.13)$$

$$0 = \frac{\alpha}{M} \bar{n}^{\alpha-1} - \bar{w} - [1 - \delta(1-s)] \frac{c}{q(\bar{\theta})} \quad (5.14)$$

$$\bar{a} = 1 \quad (5.15)$$

$\check{x}_t \equiv d \ln(X_t)$ 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:

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

- Law of motion of employment:

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

- Resource constraint:

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

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

- Production constraint:

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

- Wage rule:

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

- Firm's Euler equation:

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

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

- Productivity shock:

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

Appendix 5.C Tables and Graphs

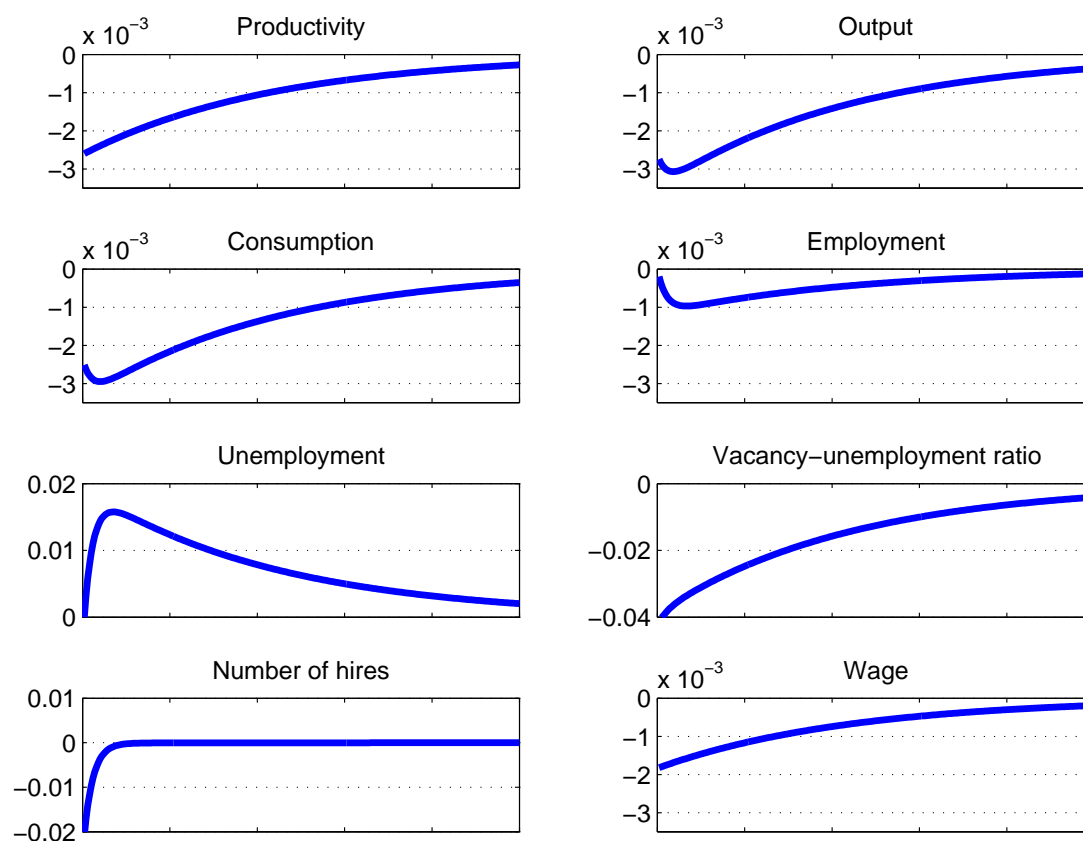


Figure 5.1: IRFs to negative technology shocks of one standard deviation. Impulse response functions (IRFs) represent the log-deviation from steady-state for each variable. IRFs are obtained by log-linearizing the model, as detailed in Appendix 5.B. The total time period displayed on the x-axis is 250 weeks. The shock imposed to technology is $-\sigma = -0.0026$.

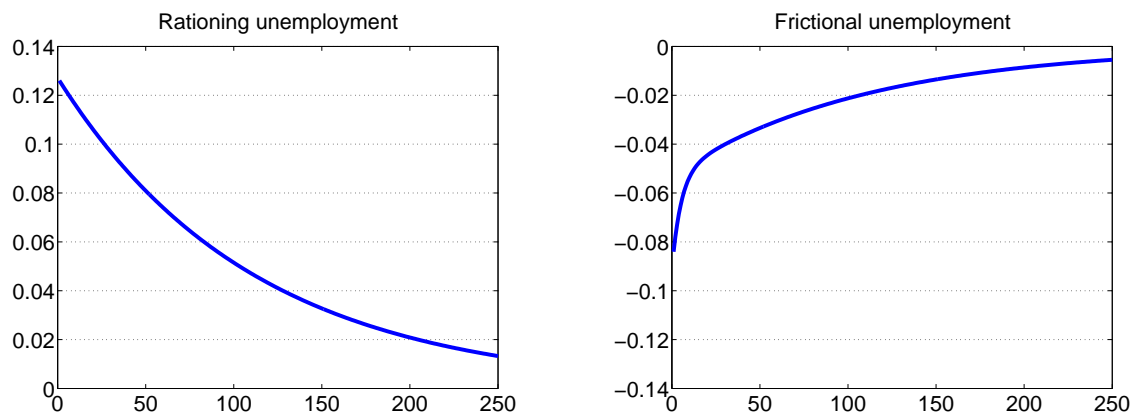


Figure 5.2: IRF of rationing and frictional unemployment to negative technology shock. Impulse response functions (IRFs) represent the log-deviation from steady-state for each variable. IRFs are obtained by log-linearizing the model, as detailed in Appendix 5.B. The time period on the x-axis is a week. The shock imposed to technology is $-\sigma = -0.0026$.

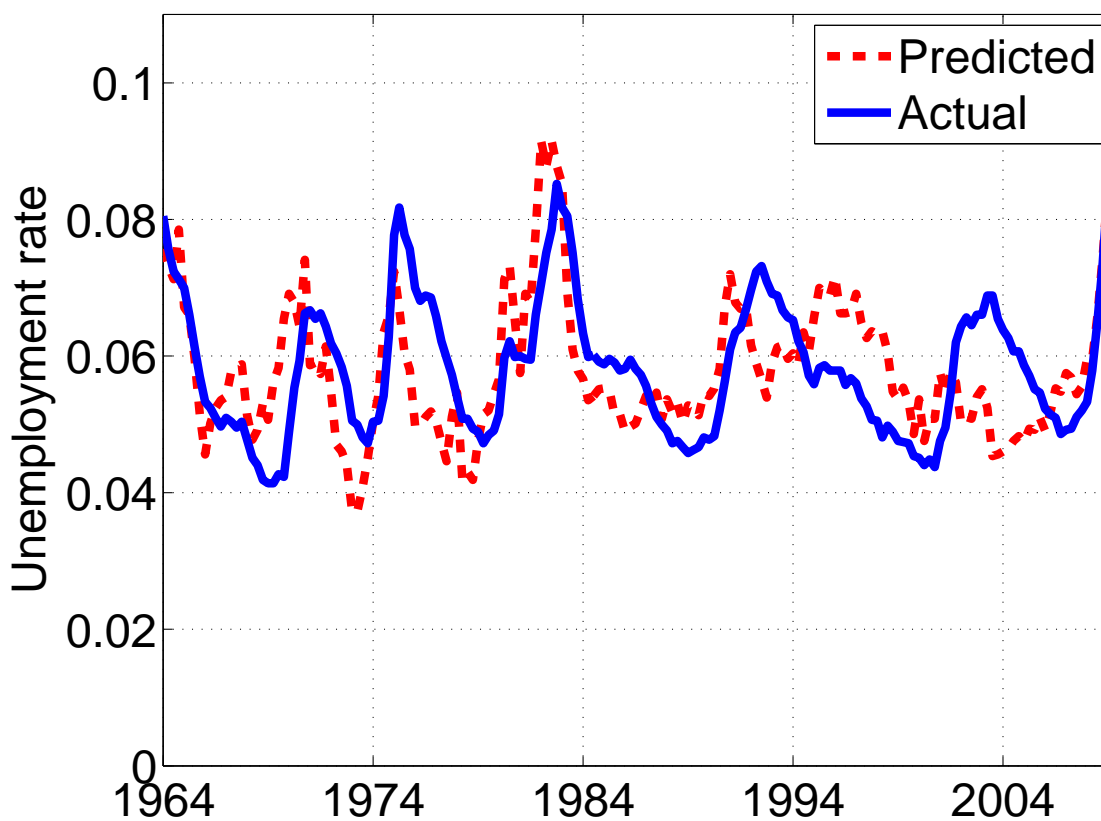


Figure 5.3: Actual unemployment, and model-generated unemployment under actual technology shocks from U.S. data, 1964–2009. Actual unemployment is the quarterly average of seasonally-adjusted monthly series constructed by the BLS from the CPS. The top graph compares actual unemployment with the unemployment series generated when the nonlinear model is stimulated by the quarterly technology series constructed in Section 5.4.1 using output and employment data provided by the BLS. Productivity and actual unemployment are detrended with a HP filter with smoothing parameter 10^5 . The time period is 1964:Q1–2009:Q2. The construction of model-generated unemployment is detailed in Section 5.6.1.

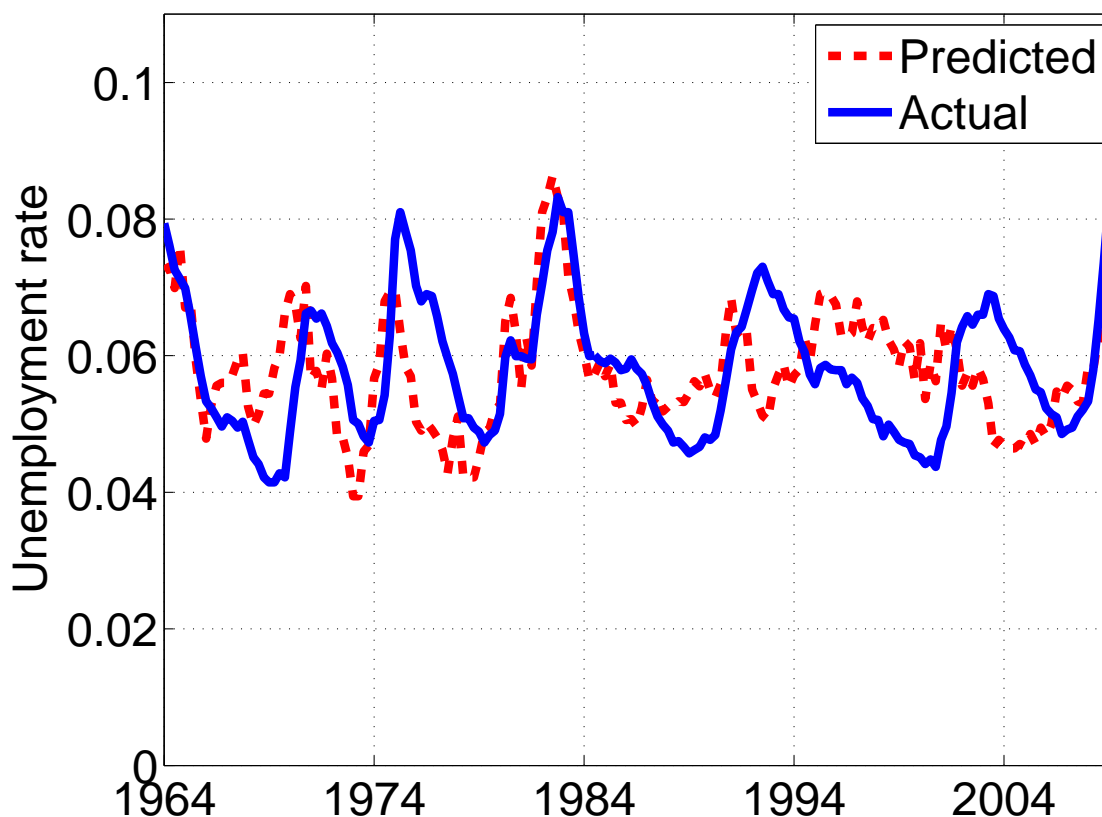


Figure 5.4: Actual unemployment, and model-generated unemployment under actual TFP shocks from U.S. data, 1964–2009. Actual unemployment is the quarterly average of seasonally-adjusted monthly series constructed by the BLS from the CPS. The graph compares actual unemployment with the unemployment series generated when the nonlinear model is stimulated by the quarterly, utilization-adjusted TFP series constructed by Fernald (2009). TFP and actual unemployment are detrended with a HP filter with smoothing parameter 10^5 . The time period is 1964:Q1–2009:Q2. The construction of model-generated unemployment is detailed in Section 5.6.1.

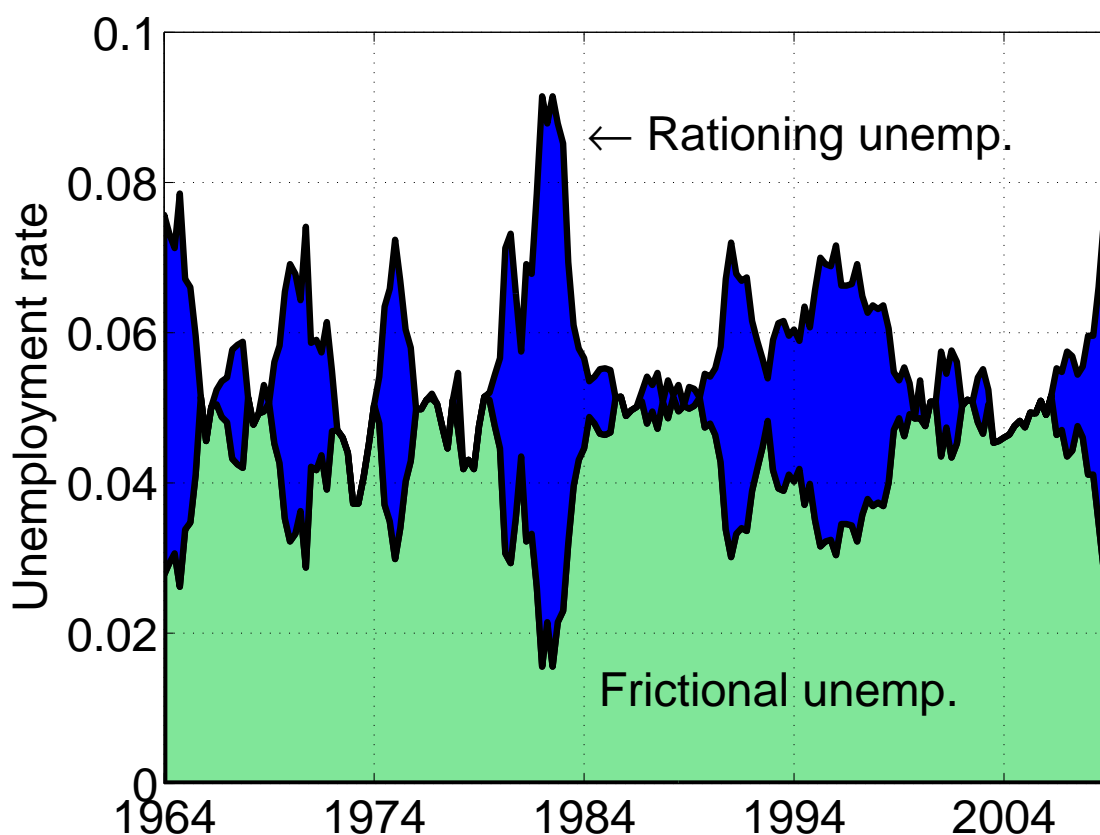


Figure 5.5: Decomposition of model-generated U.S. unemployment, 1964–2009. The graph decomposes the unemployment series generated when the nonlinear model is stimulated by the quarterly technology series constructed in Section 5.4.1 using output and employment data provided by the BLS. Productivity, TFP, and actual unemployment are detrended with an HP filter with smoothing parameter 10^5 . The time period is 1964:Q1–2009:Q2. The construction and decomposition of model-generated unemployment, as well as the decomposition of actual unemployment, are detailed in Sections 5.6.1 and 5.6.2.

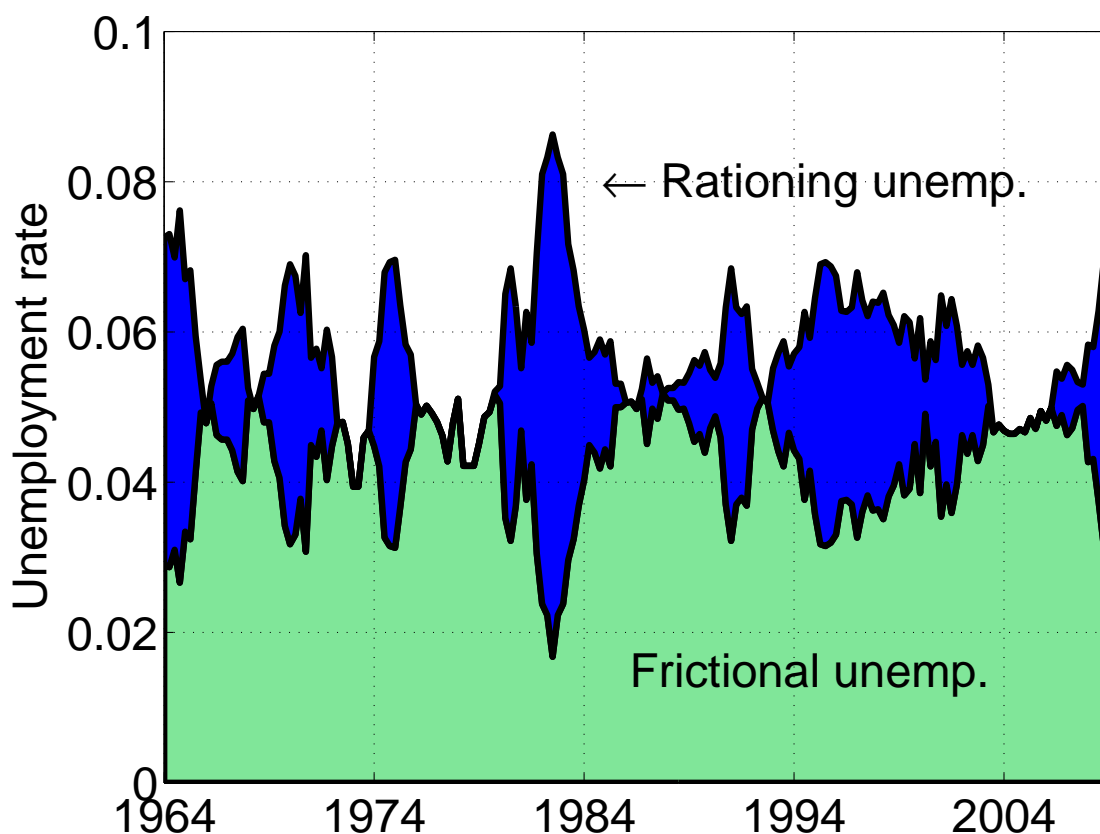


Figure 5.6: Decomposition of model-generated U.S. unemployment, 1964–2009. The graph decomposes the unemployment series generated when the nonlinear model is stimulated by the quarterly, utilization-adjusted TFP series constructed by Fernald (2009). TFP and actual unemployment are detrended with an HP filter with smoothing parameter 10^5 . The time period is 1964:Q1–2009:Q2. The construction and decomposition of model-generated unemployment, as well as the decomposition of actual unemployment, are detailed in Sections 5.6.1 and 5.6.2.

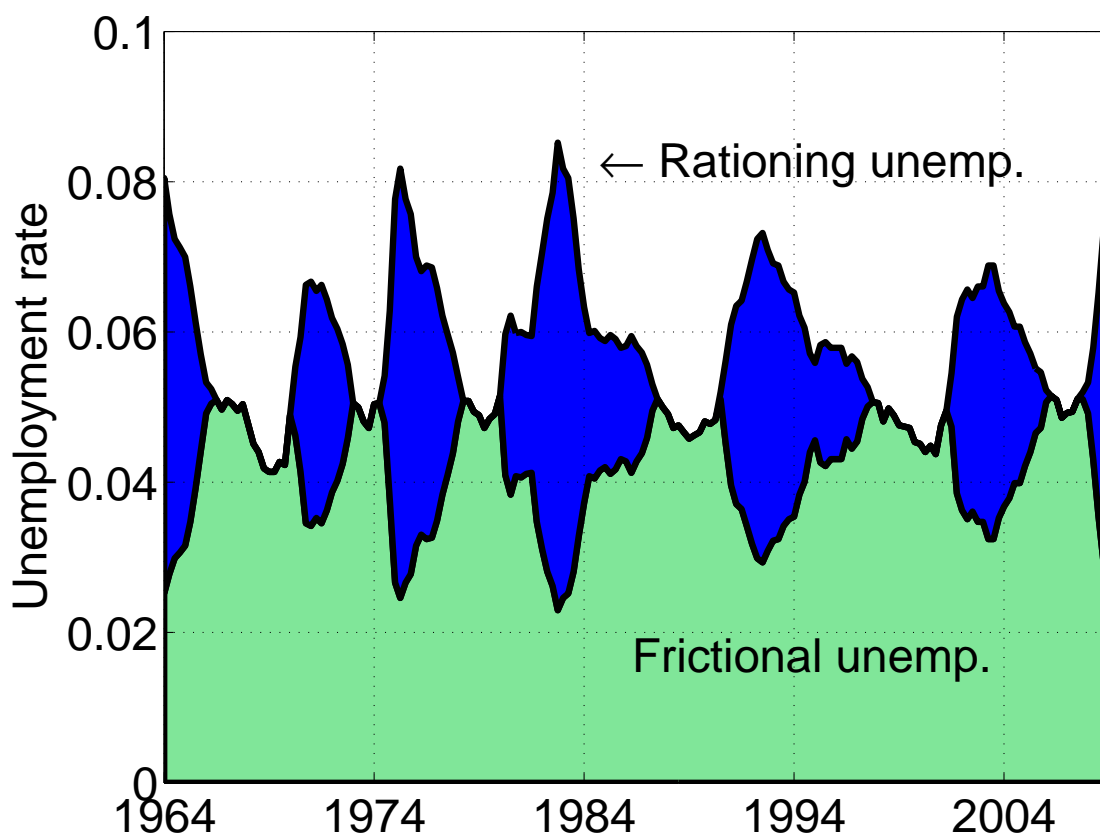


Figure 5.7: Decomposition of actual U.S. unemployment, 1964–2009. The graph decomposes actual unemployment, which is the quarterly average of seasonally-adjusted, monthly series constructed by the BLS from the CPS. Productivity, TFP, and actual unemployment are detrended with an HP filter with smoothing parameter 10^5 . The time period is 1964:Q1–2009:Q2. The construction and decomposition of model-generated unemployment, as well as the decomposition of actual unemployment, are detailed in Sections 5.6.1 and 5.6.2.

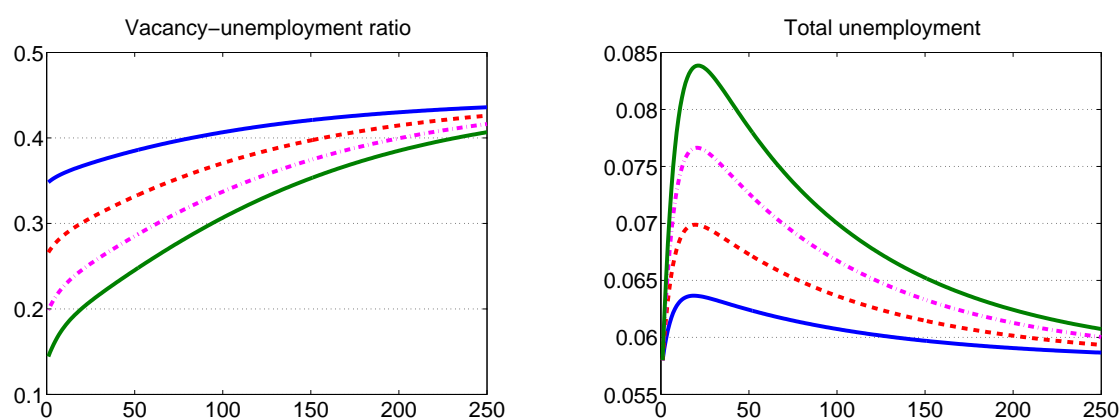


Figure 5.8: Exact response of labor market variables to negative technology shocks. Response functions represent the evolution of labor market tightness, unemployment and its components (in percentage of the labor force) when a negative technology shock hits the economy. The dark (blue) solid line is the response to a 5-standard-deviation shock; the dashed line to a 10-standard-deviation shock; the dot-and-dash line to a 15-standard-deviation shock; and the light (green) solid line to a 20-standard-deviation shock. A standard deviation for technology shock is $\sigma = 0.0026$. The time period on the x-axis is a week. The response functions are obtained with a shooting algorithm, as described in Section 5.5.4.

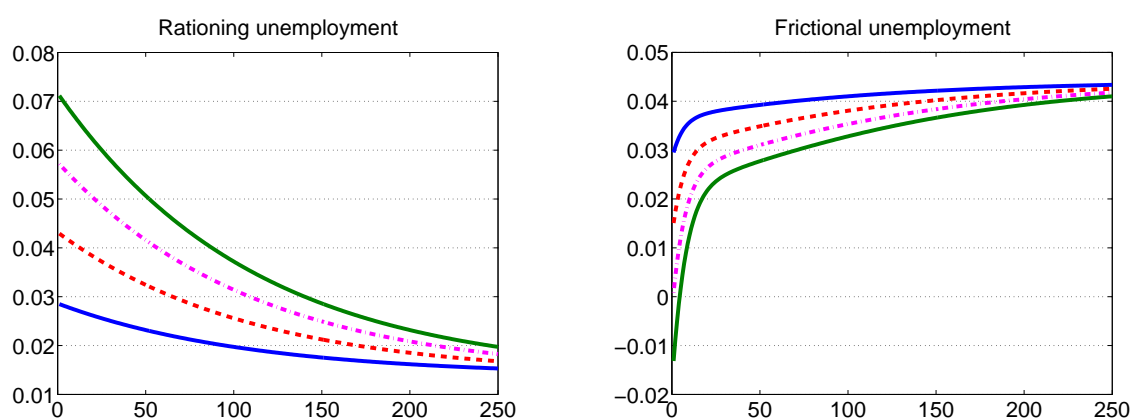


Figure 5.9: Exact response of unemployment components to negative technology shocks. Response functions represent the evolution of labor market tightness, unemployment and its components (in percentage of the labor force) when a negative technology shock hits the economy. The dark (blue) solid line is the response to a 5-standard-deviation shock; the dashed line to a 10-standard-deviation shock; the dot-and-dash line to a 15-standard-deviation shock; and the light (green) solid line to a 20-standard-deviation shock. A standard deviation for technology shock is $\sigma = 0.0026$. The time period on the x-axis is a week. The response functions are obtained with a shooting algorithm, as described in Section 5.5.4.

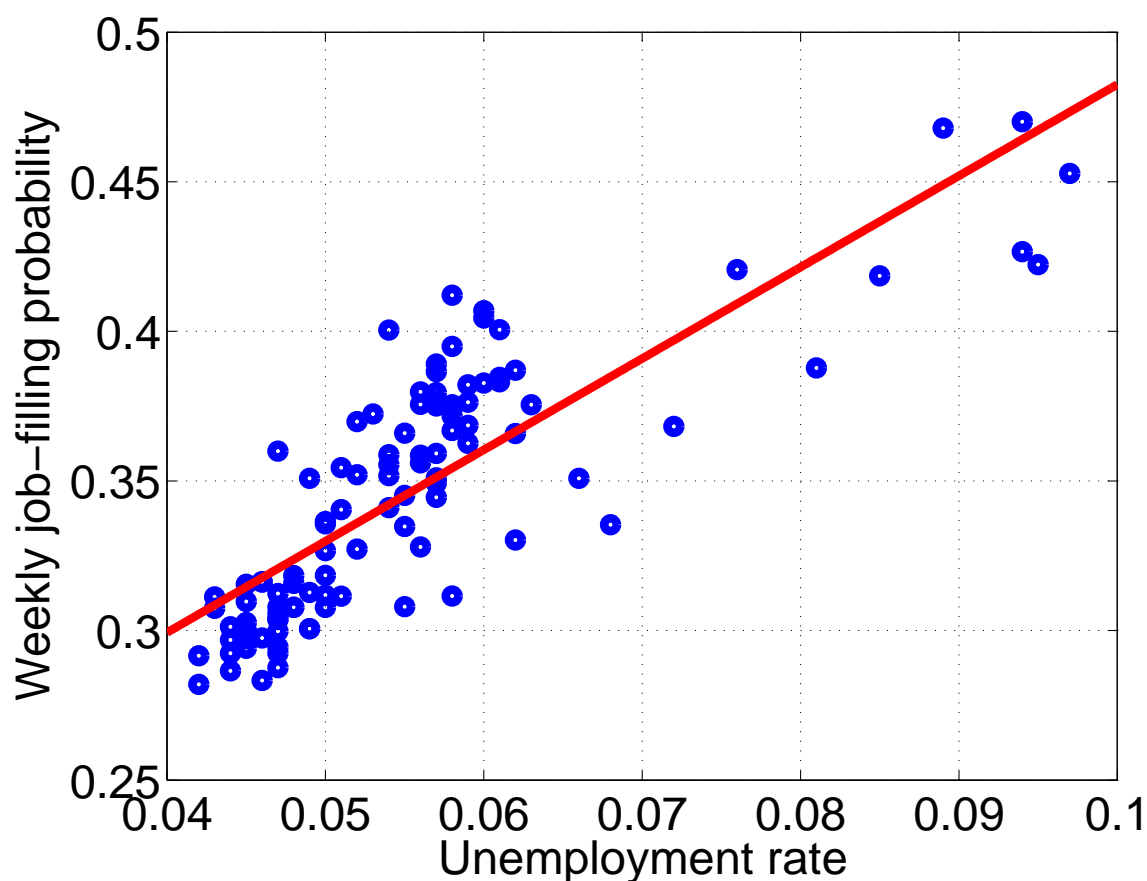


Figure 5.10: Weekly job-filling probability as a function of the unemployment rate in the U.S., 2001–2009. Unemployment is seasonally-adjusted, monthly series constructed by the BLS from the CPS. The job-filling-probability series is a monthly series constructed as $1/4$ of the ratio of a seasonally-adjusted, monthly, number-of-hire series by a seasonally-adjusted, monthly, number-of-vacancy series. Both the number-of-hire and number-of-vacancy series are constructed by the BLS from JOLTS. The time period is 2001:M1–2009:M8. The graph also shows a linear trend for the job-filling probability.

	Interpretation	Value	Source
s	Separation rate	0.95%	JOLTS, 2000–2009
δ	Discount factor	0.999	Corresponds to 5% annually
ω	Efficiency of matching	0.23	JOLTS, 2000–2009
η	Elasticity of job-filling	0.5	Petrongolo and Pissarides (2001)
$\mathbb{E}[a]$	Mean technology	1	Normalization
ρ	Autocorrelation of technology	0.991	MSPC, 1964–2009
σ	Conditional variance of technology	0.0026	MSPC, 1964–2009
w_0	Steady-state real wage	0.67	Matches unemployment = 5.8%
α	Returns to labor	0.74	Matches labor share = 0.66
M	Markup	1.11	Christiano et al. (2005)
γ	Real wage rigidity	0.70	Haefke et al. (2008)
c	Recruiting costs	0.21	$0.32 \times \bar{w}$

Table 5.1: Parameter values in simulations. Section 5.4 provides details on the calibration strategy. All parameters are calibrated at weekly frequency.

$\log(w_t)$	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$\log(a_t)$	0.44 (0.07)	0.28 (0.10)	0.22 (0.04)	0.62 (0.08)	0.30 (0.25)	0.42 (0.07)	0.45 (0.05)
R^2	0.19	0.18	0.04	0.27	0.10	0.15	0.32
Number obs.	182	34	182	182	33	182	182

Table 5.2: Estimation of the wage schedule with U.S. data. This table presents the results from regressions of log real wage on log technology. Standard errors of the estimates are in parenthesis. All series used are seasonally adjusted. Column (1) is the preferred specification. w_t is average hourly earning in the nonfarm business sector, constructed by the Bureau of Labor Statistics (BLS) Current Employment Statistics (CES) program, and deflated by the Consumer Price Index (CPI) for all urban households constructed by BLS. Average hourly earning is a quarterly series. CPI is a quarterly average of monthly series. $\log(a_t)$ is computed as the residual $\log(y_t) - \alpha \cdot \log(n_t)$. y_t and n_t are quarterly real output and employment in the nonfarm business sector, respectively, and are constructed by the BLS Major Sector Productivity and Costs (MSPC) program. The sample period is 1964:Q1–2009:Q2. Columns (2)–(7) perform robustness checks. (2) and (3) estimate the regression with alternative measures of real wage. In (2), w_t is the compensation of private industry workers, which is part of the Employment Cost Index (ECI) constructed by the BLS, deflated by the CPI. The ECI is a measure of the change in the cost of labor, free from the influence of employment shifts among occupations and industries over the business cycle. Compensation of private industry workers is a quarterly series. The sample period is 2001:Q1–2009:Q2 (the longest period for which ECI is available). In (3), w_t is real compensation constructed by the BLS MSPC program. This is a quarterly series, and the sample period is 1964:Q1–2009:Q2. Columns (4)–(6) estimate the regression with alternative measures of technology. In (4), a_t is purified TFP at yearly frequency, constructed by Basu, Fernald, and Kimball (2006). The sample period is 1964–1996. In (5), $\log(a_t)$ is computed as $\log(y_t) - \alpha \cdot \log(h_t)$, in which h_t is quarterly hours worked in the nonfarm business sector, constructed by the BLS MSPC program. The sample period is 1964:Q1–2009:Q2. In (6), $\log(a_t)$ is simply computed as $\log(y_t) - \log(n_t)$. The sample period remains 1964:Q1–2009:Q2. The quarterly series $\log(w_t)$ and $\log(a_t)$ are detrended using an HP filter with smoothing parameter 10^5 in all regressions, except in (4) and (7). In (4), I use a smoothing parameter of 500 because the series are at yearly frequency. In (7), I use a smoothing parameter of 1,600 in a regression otherwise similar to (1), as a robustness check.

	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

Table 5.3: Summary statistics, quarterly U.S. data, 1964–2009. 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 Job Openings and Labor Turnover Survey (JOLTS), and data from the Conference Board, as explained in Section 5.5.3. Labor market tightness θ is the ratio of vacancy level to unemployment level. 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 $\log(Y) - \alpha \cdot \log(N)$, as explained in Section 5.4.1. 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 .

	U	V	θ	W	Y	a
Standard Deviation	0.133 (0.020)	0.159 (0.021)	0.287 (0.041)	0.013 (0.002)	0.024 (0.004)	0.018 (0.003)
Autocorrelation	0.928 (0.024)	0.830 (0.051)	0.900 (0.033)	0.870 (0.042)	0.888 (0.037)	0.870 (0.042)
	1	-0.922 (0.022)	-0.978 (0.007)	-0.985 (0.005)	-0.993 (0.002)	-0.985 (0.005)
	—	1	0.985 (0.004)	0.933 (0.020)	0.921 (0.024)	0.933 (0.020)
	—	—	1	0.974 (0.008)	0.971 (0.009)	0.974 (0.008)
Correlation	—	—	—	1	0.997 (0.001)	1.000 (0.000)
	—	—	—	—	1	0.997 (0.001)
	—	—	—	—	—	1

Table 5.4: Simulated moments in the log-linearized model. 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 200 model simulations) are reported in parentheses. Section 5.5.3 provides details on the simulation. Appendix 5.B describes the log-linearized equilibrium conditions.

	Mean	Std. dev.	Autoc.	Correlation		
				U	U^C	U^F
U	0.059 (0.004)	0.013 (0.002)	0.901 (0.028)	1	0.969 (0.023)	-0.789 (0.162)
U^C	0.020 (0.006)	0.021 (0.004)	0.888 (0.034)	—	1	-0.914 (0.075)
U^F	0.039 (0.002)	0.008 (0.001)	0.843 (0.048)	—	—	1

Table 5.5: Simulated moments in the nonlinear model. Results from simulating the nonlinear model with stochastic technology. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 5.6.3 provides details on the simulation algorithm, and the stochastic process for technology.

Chapter 6

Optimal Dynamic Unemployment-Reducing Policies

6.1 Introduction

This dissertation proposes a model of the labor market integrating matching frictions and job rationing. The previous chapters argued that this integration provides a new understanding of business-cycle fluctuations in the labor market: during a recession, the rise in total unemployment is driven by an increase in job rationing; at the same time, frictional unemployment decreases. In this chapter, I study the implications of fluctuations in rationing unemployment and frictional unemployment for the optimal design of unemployment-reducing labor market policies. I show that novel policy recommendations arise in this framework. The optimal unemployment-reducing policy evolve over the business cycle: it puts more weight in good times than in bad times on policy instruments reducing matching frictions; conversely, it puts more weight in bad times than in good times on policy instruments creating jobs directly. Since governments have not reached a consensus about the best policies to combat cyclical fluctuations in unemployment and are faced with high, lingering unemployment in 2010, these findings are particularly important and timely.¹

I use the dynamic stochastic general equilibrium model specified in Chapter 5, but for one modification: I assume that the household is risk averse, which makes the environment more interesting for policy analysis. I first compute the second-best allocation, which is the optimal allocation implemented by a benevolent social planner who wants to maximize social

¹The Wall Street Journal had an article in November 2009 asking: “With the U.S. unemployment rate at 10.2% and rising, pressure on the government to do something to create jobs is mounting. The question is what the U.S. government can, should and will do about it.” At the same time, The Economist had an article on November 5th, 2009, titled “Pay for Delay” comparing policy responses across Western countries in response to the surge in unemployment observed in 2008 and 2009, and pointing at the lack of consensus in terms of policy response across countries.

welfare subject to the technological production and matching constraints. I assume that the social planner is not subject to the organizational or institutional constraints that impose wage rigidity in the decentralized economy. I use the second-best allocation as benchmark to measure the welfare cost of unemployment in the decentralized economy, prior to policy intervention on the labor market. I find that the output loss is large—more than 3% of output on average. This quantitative result suggest that large welfare gains may be achieved by implementing unemployment-reducing labor market policies.

Next, I propose an integrated treatment of the design of unemployment-reducing labor market policies in a model with matching frictions and job rationing. Models based on search theories have been specifically designed to study particular labor market policies, but these policies have never been compared.² In addition, these studies do not emphasize the variations in the effectiveness of these policies at different points of the business cycle. To combat inefficiencies associated with search externalities, wage rigidity, and firms' monopoly power, I focus on three unemployment-reducing policies. The first one is direct employment. It hires unemployed in public-sector jobs, or contracts with private-sector firms to produce goods consumed by government (infrastructure, public services), in order to hire workers. Since there is a shortage of job in the economy, it is natural to try and create more jobs. The second policy is a placement service, which enhances job-search efficiency of unemployed workers and monitors their search effort. This policy aims to alleviate unemployment caused by frictions. The third policy is a wage subsidy. Since job rationing is in part due to high wages, it is natural to try to reduce labor costs for firms. These labor market policies are history contingent—they are fully contingent on the history of realizations of shocks—and they are taken as given by firms and household. Moreover, I follow Chari et al. (1991) and Aiyagari et al. (2002) and assume that an institutional arrangement exists through which the government can bind itself to the policy plan. Therefore, I say nothing about the issues associated with time consistency of governmental policy studied in Kydland and Prescott (1977), Kydland and Prescott (1980), and Lucas and Stokey (1983).

Historically, governments have resorted to these policies on a large scale. Direct employment was used by the Roosevelt administration to hire millions of unemployed to build dams, bridges, and roads during the Great Depression (Fishback et al. 2003). In the current U.S. stimulus package, the Obama government is contracting large infrastructure projects, which

²For instance, Pissarides (2000) studies whether various taxes and subsidies can remove inefficiencies caused by search externalities in a simple MP model. Based on Yavaş's (1994) work, Cahuc and Zylberberg (2004) study the role for placement agencies in a search-and-matching model. A fraction of the unemployed use the services from placement agencies, which offer a different matching technology: agencies can locate immediately vacancies, but they incur fixed costs as well as variable costs based on their number of users. Their results hinge on the size of the fixed costs and the congestion effects among agency users. Last, Holmlund and Linden (1993) study the macroeconomic impact of temporary public employment in a static MP model. These public jobs are conceived as steps to regular employment, and are not regular jobs. On-the-job search among relief workers is facilitated, and the results rely heavily on search effectiveness among program participants.

puts unemployed workers back into the workforce. A more effective placement service was implemented in Germany by the “Hartz reform” from 2003 to 2005, to improve matching between employers and jobseekers (Fahr and Sunde 2009). In France, a centralized agency (the ANPE) used to collect job vacancies, collect job applications, and provide counseling and monitoring to improve matching. Lastly, France implemented reduced payroll taxes for lower-wage jobs (Cahuc and Zylberberg 2004). Belgium also implemented a reduction in payroll taxes across the board to reduce job destruction and increase job creation in 2008. Wage subsidies conditional could also be conditional on hiring new workers. Such a tax credit for employers if they increased the size of their work force or added significant hours of work as proposed by President Obama in December. More generally, Kluve et al. (2007) explain that these three policies are the most commonly used by European states, along with training programs. This paper focuses on these three categories because they are more amenable to reducing unemployment in recessions.³

I assume that the government finances these policies by issuing one-period state-contingent debt, and from a stochastic stream of income. Following the literature, I introduce government debt to allow for other possibilities than a continuously balanced government budget. The stream of income received by the government can be interpreted as income from lump-sum taxation of labor income, since household members supply labor inelastically in this model. The variation in amounts that can be taxed could result from political or legislative constraints: for instance, it may take time to vote a law to increase tax rates, the government may not have enough support to pass such a law, the proximity of elections may deter the government from increasing taxes, tax income may be devoted to other priorities than the labor market. In this model, income from taxation is seen as exogenous, while issuance of debt and spending on policy are endogenous.

The cyclical fluctuations in rationing and frictional unemployment suggest that optimal unemployment-reducing policies should adapt to the changing state of the labor market. To formalize this intuition, I compute state-dependent fiscal multipliers—the increase in social welfare obtained by spending one dollar on a policy. I prove theoretically that placement services are more effective in good times than in bad times. The converse is true of direct employment. Intuitively, in bad times, frictional unemployment is low; placement services aim to further reduce this component and are therefore ineffective. The effectiveness of direct employment is a function of how much it crowds private employment out; in bad times, competition for workers is weak and crowding out is limited; thus, this policy is effective. In the calibrated model, wage subsidies are also more effective in bad times than in good times.

³Generally, training takes one of two forms (Raaum et al. 2002). Short-term training prevents social isolation during non-employment and in turn enhances job search efficiency. In this case, training has effects similar to a placement service. Long-term training, on the other hand, increases human capital and increases productivity. It lowers unemployment only in the long run, and could not be used to fight cyclical fluctuations in unemployment.

Then I characterize the optimal mix of policies implemented by a benevolent social planner by solving a Ramsey problem. The Ramsey problem is to choose labor market policies to maximize the household's expected utility subject to three constraints: (i) the optimality conditions for firms and household in the decentralized equilibrium with policies; (ii) the government's budget constraint; and (iii) the resource constraint in the economy. The optimal unemployment-reducing policy evolve over the business cycle: its puts more weight on policy instruments reducing matching frictions (placement services) in good times than in bad times; conversely, it puts more weight on policy instruments creating jobs directly (direct employment and a wage subsidy) in bad times than in good times. Intuitively, the optimal unemployment-reducing policy should adapt to the state of the labor market because of the cyclical fluctuations in the sources of unemployment.

6.2 Some Stylized Facts

This section argues that governments have not reached a consensus about the best policies to combat unemployment fluctuations. It also argues that governments do not seem to adjust their labor market policies to the state of the labor market.

The level and composition of spending on labor market policies designed to reduce joblessness vary widely among OECD countries. Figure 6.2 summarizes OECD data for public expenditures on labor market policies in 2007. Spending can be as high as 3.3% of GDP in Belgium, and as low as 0.5% of GDP in the U.K. These differences cannot be explained by different positions in the business cycle: between 2005 and 2006, unemployment increased by 0.6% in the U.K., while it fell by 0.2% in Belgium. Moreover, a closer look at the composition of spending on active labor market policies (ALMP) in the same countries shows that it is very heterogeneous and seemingly unrelated to the position in the business cycle. For instance, France, Ireland, and new Zealand were all in a period of relatively constant unemployment between 2005 and 2007. However, the same OECD data show that in 2007, France allocated 16% of its spending on ALMP to placement services, 14% to employment subsidies, and 22% to direct job creation; for Ireland, the corresponding numbers are 6%, 6%, and 34% respectively; and for New Zealand, they are 3%, 3% and 0% respectively. These variations could be partly explained by differences in labor market structure across countries, but a closer a look at the experiences of individual countries suggests that these heterogeneity is most likely due to policy experimentation, or changes in beliefs of politicians.

Looking at time series of spending on ALMP in specific countries suggest that these policies are not contingent on the state of the labor market. Figure 6.3 decomposes spending on ALMP in the U.S. in the 1985–2007 period, and Figure 6.4 repeats the same exercise for France. In the U.S., spending on ALMP continuously declined from 0.25% of GDP to less than 0.15% between 1985 and 2007 in spite of burst in unemployment in the early 1990s and early 2000s; that is, the U.S. government did not respond to cyclical variations in unem-

ployment. In the meantime, spending on ALMP in France grew from 0.6% of GDP to more than 1.2% of GDP in 1999, in response of rise of unemployment in mid-1990s. The composition of French spending fluctuated over the period: the implementation of wage subsidies for low-wage jobs in 1995 led the share of spending on employment subsidies to increase in the mid-1990 and reach a quarter of total ALMP spending in 1997, before decreasing; the implementation of a scheme to offer social jobs to young workers—the *emplois jeunes*—led the share of spending on direct job creation to increase and spike in early 2000s, reaching a third of ALMP spending, before decreasing. These policy changes are only vaguely related to business-cycle fluctuations. Instead, they correspond to changes of political leadership in France.

6.3 A Model with Unemployment-Reducing Policies

This model is very similar to the general model presented in Chapter 3. I highlight below the major differences: risk-aversion, and the presence of government policies and government debt.

6.3.1 Sources of fluctuations

Fluctuations are driven by technology, which follows a stochastic process $\{a_t\}_{t=0}^{+\infty}$, and by the income available to the government for spending on policies, which follow a stochastic process $\{i_t\}_{t=0}^{+\infty}$. In this model, good times are periods with high technology and high income available to the government. Conversely, bad times are periods with low technology and low income for the government. Let $s_t = (a_t, i_t)$ be the state of the economy in period t . The unconditional probability of observing an history s^t is given by the probability measure $\mu_t(s^t)$.

Firms and household make decisions whose time t components are functions of the history of events $s^t = (s_0, s_1, \dots, s_t)$, and of the initial employment level in the economy N_{-1} , and the initial indebtedness of the government $b_{G,-1}$.⁴

6.3.2 Households

The household is risk-averse and ranks consumption streams according to

$$\mathbb{E}_0 \sum_{t=0}^{+\infty} \delta^t \cdot \frac{(C_{P,t} + C_{G,t})^{1-\phi}}{1-\phi}, \quad (6.1)$$

⁴All firms are assumed to initially have the same size, so that N_{-1} determines initial employment in each firm.

where $\phi \in [0, 1]$, $\delta \in (0, 1)$ is the discount rate. $C_{P,t}$ is the Dixit-Stiglitz composite consumption index defined by:

$$C_{P,t} = \left(\int_0^1 C_{P,t}(i)^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)},$$

where $\epsilon \in (1, +\infty)$, and $C_{P,t}(i)$ is the quantity of good $i \in [0, 1]$ consumed in period t . $C_{G,t}$ is defined similarly:

$$C_{G,t} = \left(\int_0^1 C_{G,t}(i)^{(\epsilon-1)/\epsilon} di \right)^{\epsilon/(\epsilon-1)}$$

where $C_{G,t}(i)$ is the quantity of good $i \in [0, 1]$ provided by the government, and consumed in period t . For simplicity, I assume that aggregate private consumption $C_{P,t}$ and aggregate public consumption $C_{G,t}$ are perfect substitute. Thus, social welfare only depends on total consumption. The price of good i is $P_t(i)$ and the aggregate price index is

$$P_t = \left(\int_0^1 P_t(i)^{\epsilon-1} di \right)^{1/(\epsilon-1)} = 1.$$

All household members participate in the labor market, and supply labor inelastically. The household has employed workers in all firms, and unemployed workers searching for a job. Household members pool their income before choosing consumption and asset holding. The household buys state-contingent securities with one-period maturity issued by the government. $b_t(s_{t+1})$ is the amount of contingent debt bought in period t , and $Q_t(s_{t+1})$ is the price of the state-contingent asset traded by government, in terms of time t good. They face a sequence of budget constraint:

$$\int_0^1 \frac{P_t(i)}{P_t} \cdot C_{P,t}(i) di + \sum_{s_{t+1}} Q_t(s_{t+1}) b_t(s_{t+1}) = W_t \cdot N_t + b_{t-1}(s_t) + \pi_t - i_t, \quad (6.2)$$

for all t and all s^t . W_t is the average real wage paid by firms, $W_t \cdot N_t$ is total wage income, π_t denotes aggregate dividend payments received from firms, and i_t is a random lump-sum transfer to the government. I assume for simplicity that public-sector production $C_{G,t}$ is given away for free to households, and thus does not enter the budget constraint.

6.3.3 Labor Market

Workers can be hired by a continuum of firms indexed by $i \in [0, 1]$. At the beginning of period t , $T_{P,t} = \int_0^1 T_{P,t}(i) di$ workers are employed in private firms. At the same time, $T_{G,t}$ workers are employed by the government to offer placement services to the unemployed or to work on contracts for the government. Thus, there are $T_t \equiv T_{P,t} + T_{G,t}$ incumbents at the beginning of period t , and a pool $U_t = 1 - T_t$ of unemployed workers looking for a job

(beginning-of-period unemployment).

Firm i decides how many workers $H_{P,t}(i)$ to recruit. The aggregate number of workers recruited by private firms is $H_{P,t} = \int_0^1 H_{P,t}(i) di$. The government decides to hire $H_{G,t}$ workers to work on government contracts in private firms, and to work in placement services. $H_t \equiv H_{P,t} + H_{G,t}$ is the total number of new hires in period t .

The number of workers now employed in firm i is $N_{P,t}(i) = T_{P,t}(i) + H_{P,t}(i)$. The total number employed by the government is $N_{G,t} = T_{G,t} + H_{G,t}$.

$$G_t \equiv (1 - \zeta_t)T_{G,t} + H_{G,t}$$

of these government workers are employed in private firms to work for the government, and a fraction $\zeta T_{G,t}$ are employed by the government to improve matching ($\zeta \in [0, 1]$). $N_t \equiv N_{P,t} + N_{G,t}$ is the total number of employees in period t . $H_{G,t}$ is first control variable: the government decides how many new workers to have in contracting jobs.

At the end of period t , a fraction s of all existing jobs are destroyed for exogenous reasons. I assume that workers who lost their job at the end of one period can apply for a new job immediately at the beginning of the next period.

The government hires workers in placement agencies to improve matching and reduce recruiting costs. At the beginning of period t , there are U_t unemployed and $\zeta_t \cdot T_{G,t}$ workers in placement agencies. I define m_t , the ratio of placement workers to unemployed:

$$m_t \equiv \frac{\zeta_t \cdot T_{G,t}}{U_t} \tag{6.3}$$

Placement-agency workers are employed to facilitate matching. They do not produce any output, but they are more efficient at searching for jobs and creating matches than unemployed workers. The government intervention to improve matching in fact allocates m_t placement-agency workers per unemployed. I assume it increases jobseekers' search intensity from 1 to $1 + \psi m_t$. $\psi > 1$ is the relative search efficiency of placement-agency staff. From a matching point of view, having the unemployed search more efficiently is equivalent to having more unemployed searching: the effective number of jobseekers becomes $(1 + \psi m_t) \cdot U_t$; this implies that recruiting is less costly for firms even if the same number of vacancies and unemployed try to locate each other. $m_t \in [0, \frac{T_{G,t}}{U_t}]$ is new control variable for government. I can now define implicitly the labor market tightness θ_t with:

$$f(\theta_t, m_t) = f((1 + \psi \cdot m_t)U_t, V_t) = \frac{H_t}{U_t} \tag{6.4}$$

Recruiting is costly, because there are search frictions on the labor market. Private firms and the government open vacancies at the beginning of each period. Each vacancy is filled for sure with a suitable worker by the end of the recruiting period. Search frictions

make recruiting increasingly costly as the labor market becomes tighter, i.e. as the ratio of new recruits to jobseekers increases. When resources are allocated to a placement agency, matching becomes more efficient, firms recruit more easily, and the expected recruiting costs fall. The recruiting cost for any job in terms of aggregate consumption is:

$$R(\theta_t, m_t, s_t) = \frac{c \cdot a_t}{q(\theta_t, m_t)} \quad (6.5)$$

$$q(\theta_t, m_t) = \frac{f(\theta_t, m_t)}{\theta_t}. \quad (6.6)$$

$1/q(\theta_t, m_t)$ reflects the recruiting efforts the firm must provide to fill a vacancy for sure. All jobs are the same in this economy: jobs in private firms on government contracts, placement-agency jobs, and regular private jobs. Therefore, workers are indifferent between accepting any of these three kinds of jobs, and it is as costly to fill a vacancy for any of these jobs (if a job type were preferred, vacancies for this type of job would be filled more easily, and it would be less costly to recruit for this job).

6.3.4 Firms

The number of workers in the firm is:

$$N_t(i) = N_{P,t}(i) + G_t(i) \quad (6.7)$$

In period t , firm i hosts $N_{P,t}$ workers producing goods sold by the firm to households, and $G_t(i)$ workers producing goods sold to the government. I assume that private production uses the infra-marginal production capacity of firms, and that public production uses the marginal production capacity, such that private production is

$$\int_0^{N_{P,t}(i)} F'_t(x) dx = F(N_{P,t}(i), a_t)$$

Firm i sells private production to households, and sets price $P_t(i)$ for this production. It sells public production to the government. Firm i and the government bargain over the price of public production. I assume that the government has all the bargaining power, so that firm i makes zero profit on public production. Consequently, public production is bought at its cost: it is as if the government covered both the wage bill of employees of firm i working on government contracts. The recruiting costs are also paid for by the government. The government controls the number $(1 - \zeta_t)T_{G,t}(i) + H_{G,t}(i)$ of employees working on government contracts.

The firm's expected sum of discounted real profits is:

$$\mathbb{E}_0 \sum_{t=0}^{+\infty} q_t^0 \pi_t(i) \quad (6.8)$$

where $q_{t_2}^{t_1}(s^{t_2}|s^{t_1})$ is the discount factor between period t_1 and $t_2 > t_1$ constructed from the returns on state-contingent claims, and $\pi_i(t)$ is firm's real profit in period t :

$$\pi_t(i) = Y_t(i) \times \frac{P_t(i)}{P_t} - (1 - \tau_t) \cdot W_t(i) \cdot N_{P,t}(i) - R(\theta_t, c) \cdot H_{P,t}(i)$$

$Y_t(i)$ is the demand firm i faces from consumers, $\frac{P_t(i)}{P_t}$ is the relative price it sets, $W_t(i)$ is the average real wage it pays, and τ_t is the wage subsidy offered by the government to promote employment. Public production does not enter firm's profit, since the firm makes no profit on it. Moreover, since public production only uses marginal production capacity, it does not affect firm's productivity over private production. Note that $q_{t_2}^{t_1}(s^{t_2}|s^{t_1})$ is the price of an Arrow-Debreu security purchased at t_1 after history s^{t_1} , and delivering one unit of consumption at t_2 contingent on history s^{t_2} .

The firm faces a production constraint:

$$Y_t(i) \leq F(N_{P,t}(i), a_t),$$

and a constraint on the number of workers employed in period t :

$$N_{P,t+1}(i) \leq (1 - s) \cdot N_{P,t}(i) + H_{P,t+1}(i).$$

$(1 - s) \cdot N_{P,t}(i)$ is the beginning-of-period workforce in firm i .

6.3.5 Government and Labor Market Policies

Monopolistic competition, and especially real wage rigidity introduce inefficiencies in the economy. In the face of technology shocks, unemployment becomes inefficiently high. The government decides how many workers to hire $H_{G,t}$, how to split government workers between placement services and contracting work in private companies $\zeta_t \in [0, 1]$. Equivalently, the government chooses G_t and m_t . It also picks the rate of subsidy on wages τ_t .

Government debt after history s^t , contingent on s_{t+1} , is $b_{G,t}(s_{t+1})$. The government issues bonds to repay its debt and finance labor market policies, in addition to exogenous income i_t . The purchase of government debt by the household is arbitrarily bounded above and

below. The budget constraint faced by the government is

$$b_{G,t-1}(s_t) + \tau_t \cdot W_t \cdot N_{P,t} + W_t \cdot (N_{G,t}) + R(\theta_t, m_t, s_t) \cdot H_{G,t} = \sum_{s^{t+1}} Q_t(s_{t+1}) \cdot b_{G,t}(s_{t+1}|s^t) + i_t \quad (6.9)$$

Summing up all these budget constraints yields one unique intertemporal budget constraint:

$$b_{G,-1} + \sum_t \sum_{s^t} q_t^0(s^t) (\tau_t \cdot W_t \cdot N_{P,t} + W_t \cdot (N_{G,t}) + R(\theta_t, m_t, s_t) \cdot H_{G,t}) = \sum_t \sum_{s^t} q_t^0(s^t) i_t \quad (6.10)$$

under the transversality conditions that for any infinite history $s^{+\infty}$

$$\lim_{t \rightarrow +\infty} q_t^0(s^t) b_{G,t} = 0$$

where the limits are taken over sequences of histories contained in the infinite history $s^{+\infty}$.

Direct employment has two effects on unemployment. First, there is a mechanical effect: one job in the public sector brings one unemployed back into the workforce. Second, public employment crowds out private employment because recruiting efforts by the government make it more costly for private firms to enter the market, since these firms have to compete with the government for workers. When the reduction in private employment due to crowding-out is more than offset by the increase in public employment, the net effect of this policy is a reduction in unemployment. Placement service programs hire workers to staff manpower placement agencies. These workers improve matching on the labor market between jobseekers and recruiting firms through counseling or monitoring. In equilibrium, more efficient matching makes recruiting cheaper, reduces the marginal cost of labor, which leads firms to produce more and hire more workers.⁵ Finally, wage subsidies reduce the cost of labor for firms, which gives them an incentive to recruit additional workers.

6.3.6 Resource constraint

All production in the economy is constrained to be either consumed by household, consumed by the government, or allocated to recruiting:

$$Y_t = \int_0^1 C_{P,t}(i) di + \int_0^1 C_{G,t}(i) di + R(\theta_t, m_t, s_t) H_t$$

⁵One may wonder why I do not consider a private market for placement services? Clearly, the presence of private market for matching would mitigate the need for the government to provide placement services. But with matching externalities, it is unclear whether enough placement service would be provided on a private market. For instance, Yavas (1994) finds that the congestion effects on search market leads to an inefficient allocation of resources to matching, and state intervention is justified on the placement-service market.

where Y_t is total output in period t :

$$Y_t = \int_0^1 Y_t(i) di.$$

6.4 Simplifying assumptions

I now make a couple of simplifying assumptions, to make the problem more tractable. First, I make a Markov assumptions: $\mu_{t+1}(s^{t+1}) = \mu(s_{t+1}|s_t)\mu_t(s^t)$ where $\mu(s_{t+1}|s_t)$ is probability transition matrix. s_0 is given: $\mu_0(s_0) = 1$.

Moreover, I assume that job rationing results from some real wage rigidity and diminishing marginal returns to labor, as in Chapter 5. I also assume that the production function takes the simple form

$$F(N_t, a_t) = a_t \cdot N_t^\alpha.$$

and that the wage schedule is

$$W_t = w_0 \cdot a_t^\gamma.$$

Next, I assume that the matching function is Cobb-Douglas:

$$h(U_t, V_t) = \omega \cdot U_t^\eta \cdot V_t^{1-\eta} \quad (6.11)$$

Therefore the job-finding and job-filling probabilities become:

$$f(\theta_t, m_t) = \omega (1 + \psi \cdot m_t)^\eta \theta^{1-\eta} \quad (6.12)$$

$$q(\theta_t, m_t) = \omega (1 + \psi \cdot m_t)^\eta \theta^{-\eta}. \quad (6.13)$$

This specification of the job-finding and job-filling probabilities f and q as a function of the labor market tightness follow the literature (for example, Hall 2005a). The novelty is the introduction of the $(1 + \psi \cdot m_t)^\eta$ term, which reflects improved matching permitted by the placement agency. To simplify further the analysis, and consistent with empirical evidence, I assume $\eta = 1/2$ (Powers and Powers 2001). This implies $1/q(\theta) = 1/\omega^2 \cdot f(\theta) = \frac{H_t}{U_t}$.

Finally, I assume that initial government indebtedness is zero $b_{G,-1} = 0$.

6.5 Second-Best Allocation

I derive the second-best allocation by solving the problem of a social planner who chooses consumption, unemployment and labor market tightness to maximize social welfare. The planner faces the technological constraints in production and matching of the decentralized economy.

6.5.1 Definition

DEFINITION 6.1 (Allocation). An allocation is a collection of stochastic processes $\{\{N_t(i)\}_i, \{C_t(i)\}_i\}_{t=0}^{+\infty}$ whose t element must be measurable with respect to $(s^t, N_{-1}, b_{G,-1})$.

DEFINITION 6.2 (Feasible allocation). An allocation $\{\{N_t(i)\}_i, \{C_t(i)\}_i\}_{t=0}^{+\infty}$ is feasible if it satisfies the resource constraint

$$\int F(N_t(i), a_t) di = \int C_t(i) di + \frac{c}{\omega^2} \cdot a_t \cdot \frac{(N_t - (1-s)N_{t-1})^2}{1 - (1-s)N_{t-1}}. \quad (6.14)$$

DEFINITION 6.3 (Social planner's problem). The social planner chooses a feasible allocation to maximize the social welfare given by

$$\mathbb{E}_0 \sum_{t=0}^{+\infty} \delta^t \cdot \frac{C_t^{1-\phi}}{1-\phi}. \quad (6.15)$$

The t element of the social planner's choice must be measurable with respect to (a^t, N_{-1}) . I refer to the solution of the social planner's problem as the second-best allocation.

Given symmetry in preferences and technology, efficiency requires that identical quantities of each good be produced and consumed: $C_t(i) = C_t$ and $Y_t(i) = Y_t$ for all $i \in [0, 1]$. The social planner's Lagrangian can be written as a function of employment N_t only:

$$\mathbb{E}_0 \sum_{t=0}^{+\infty} \delta^t \cdot \frac{SW_t^{1-\phi}}{1-\phi} \quad (6.16)$$

where I define

$$SW_t = F(N_t, a_t) - c \cdot a_t \cdot \frac{(N_t - (1-s)N_{t-1})^2}{1 - (1-s)N_{t-1}}.$$

6.5.2 Characterization

Let me now characterize the second-best allocation. First, notice that θ_t is a function of N_t and N_{t-1} :

$$f(\theta_t) = \frac{N_t - (1-s)N_{t-1}}{1 - (1-s)N_{t-1}}.$$

Using this expression for θ_t , I get:

$$\nabla_{N_t} \theta_t = [(1 - \eta) \cdot q(\theta_t) \cdot U_t]^{-1} \quad (6.17)$$

$$\nabla_{N_{t-1}} \theta_t = -(1 - s) [1 - f(\theta_t)] [(1 - \eta) \cdot q(\theta_t) \cdot U_t]^{-1}. \quad (6.18)$$

Then, using the definition of SW_t I get:

$$\nabla_{N_t} SW_t = \alpha \cdot a_t \cdot N_t^{\alpha-1} - \frac{1}{1 - \eta} \cdot \frac{c}{q(\theta_t)} \quad (6.19)$$

$$\nabla_{N_{t-1}} SW_t = (1 - s) \left(\frac{1}{1 - \eta} \cdot \frac{c}{q(\theta_t)} - c \cdot \theta_t \cdot \frac{\eta}{1 - \eta} \right). \quad (6.20)$$

Therefore, the first-order conditions with respect to N_t is for all $t \geq 0$, all s^t , and all s_{t+1} :

$$\alpha \cdot (1 - \eta) \cdot a_t \cdot N_t^{\alpha-1} = \frac{c \cdot a_t}{q(\theta_t)} - \delta \cdot (1 - s) \cdot \mathbb{E}_t \left[\left(\frac{SW_{t+1}}{SW_t} \right)^{-\phi} \left(\frac{c \cdot a_{t+1}}{q(\theta_{t+1})} - c \cdot a_{t+1} \cdot \eta \cdot \theta_{t+1} \right) \right]. \quad (6.21)$$

In steady state, this optimality condition becomes:

$$(1 - \eta) \cdot \alpha \cdot N^{\alpha-1} = [1 - \delta \cdot (1 - s)] \frac{c}{q(\theta)} + \delta \cdot (1 - s) \cdot c \cdot \eta \cdot \theta, \quad (6.22)$$

With a linear production function ($\alpha = 1$), this expression is comparable to equation (8.5) in Pissarides (2000), which describes the efficient allocation in a standard search-and-matching model. Notice that this condition is independent of technology a , as in Blanchard and Galí (2008).

6.5.3 Steady-state

In steady-state, employment N and unemployment U are linked by

$$U = 1 - (1 - s) \cdot N, \quad (6.23)$$

and unemployment is also linked to labor market tightness θ through a Beveridge Curve:

$$U = \frac{s}{s + (1 - s) \cdot f(\theta)}. \quad (6.24)$$

In a calibrated model, I can solve the system of equations (6.22), (6.23), and (6.24), to determine the steady-state efficient levels of unemployment, employment, and labor market tightness. Under the calibration presented in Chapter 5 and summarized in Table 5.C, I find $U^* = 2.2\%$, and $\theta^* = 3.40$.

This result suggest that the actual level of unemployment observed in the data (5.8% on average in the U.S.) is too high compared to the social optimum, which is quite low at 2.2%. Some unemployment is socially optimum because too little unemployment tightens excessively the labor market, which requires the social planner to spend too much resources on recruiting. However, calibrated recruiting costs are fairly low, so that the amount of resources spent on recruiting is not large compared to aggregate output. Therefore, the social cost of unemployment because of foregone output rapidly offsets the social gains of unemployment thanks to reduced recruiting expenditures.

6.5.4 Dynamics

I now solve numerically for the dynamic second-best allocation using dynamic programming. As explained in Section 5.4.1, I estimate the technology process as an AR(1) process from the data, and approximate it as a 30-state Markov chain (Tauchen 1986, Tauchen and Hussey 1991). The two state variable are N_{t-1} and a_t , and the control variable is N_t . Use it to obtain policy function and summary statistics for optimal unemployment and labor market tightness. Using the Markov-chain approximation for technology and a discrete state space, I can compute the moments of the second-best allocation. I simulate 200 samples of 182 quarters to find that optimal unemployment varies between 2.10% and 2.25%. I estimate the empirical averages to find that $\mathbb{E}[U^*] = 2.2\%(s.e. = 0.000)$ and $\mathbb{E}[\theta^*] = 3.40(s.e. = 0.019)$. The moments are reported on Table 6.A. They indicates that second-best unemployment is about 10 times less variable than actual unemployment, second-best vacancy more than 10 times less variable. This results suggest that unemployment is too high, and much too variable because of inefficiencies: rigid wages, monopoly power. Figure 6.1 reports one such sample, with fluctuations in technology and in second-best unemployment.

6.6 Decentralized Equilibrium

This section defines and specifies a decentralized equilibrium for the model.

6.6.1 Household

DEFINITION 6.4 (Household problem). Given prices, wage, transfers, and employment $\{P_t(i), Q_t(s_{t+1}), W_t, \pi_t, N_t\}_{t=0}^{+\infty}$, the household's problem is to choose a collection of stochastic processes $\{\{C_{P,t}(i)\}_i, b_{G,t}\}_{t=0}^{+\infty}$ to maximize (3.1) subject to the sequence of budget constraints (6.2). The time t element of household's consumption choice $\{C_{P,t}(i)\}$ must be measurable with respect to $(s^t, N_{-1}, b_{G,-1})$. The time t element of household's saving choice $b_{G,t}$ must be measurable with respect to $(s^{t+1}, N_{-1}, b_{G,-1})$.

Given aggregate private consumption $C_{P,t}$, and given that the aggregate price level P_t is normalized to 1, the household's optimal demand for good i is:

$$C_{P,t}(i) = C_{P,t} \cdot P_t(i)^{-\epsilon}.$$

Then, the budget constraint can be rewritten for all t and all s^t :

$$C_{P,t} + \sum_{s_{t+1}} Q_t(s_{t+1}) b_t(s_{t+1}) = W_t \cdot N_t + \pi_t - i_t + b_{t-1}.$$

The Euler equation governing intertemporal consumption allocation is, for all t , all s^t , and all s_{t+1} :

$$Q_t(s_{t+1}) = \delta \cdot \left[\frac{\mu_{t+1}(s^{t+1})}{\mu_t(s^t)} \left(\frac{C_{P,t+1} + C_{G,t+1}}{C_t + C_{G,t}} \right)^{-\phi} \right]. \quad (6.25)$$

Q^{-1} is the return after history $s^{t+1} = (s^t, s_{t+1})$ of a state-contingent bond purchased in history s^t .

6.6.2 Firms

DEFINITION 6.5 (Firm problem). Given the wage schedule (3.7), aggregate price, labor market tightness, technology $\{P_t, \theta_t, a_t\}_{t=0}^{+\infty}$, and government policies $\{N_{G,t}(i), m_t, \tau_t\}_{t=0}^{+\infty}$, the firm's problem is to choose a collection of stochastic processes $\{N_t(i), P_t(i)\}_{t=0}^{+\infty}$ to maximize (3.8) subject to the sequence of production constraints (3.9) and recruitment constraints (3.10). The time t element of a firm's choice must be measurable with respect to $(s^t, N_{-1}, b_{G,-1})$.

In equilibrium, layoffs never occur. Therefore, firms recruit some workers each period, and the Lagrangian for the firm problem is simply:

$$\begin{aligned} \mathcal{L} = & \mathbb{E}_0 \sum_{t=0}^{+\infty} \delta^t \left\{ Y_t \cdot P_t(i)^{1-\epsilon} - (1 - \tau_t) W_t \cdot N_{P,t}(i) \right. \\ & \left. - \mathbb{I}\{N_P(i) > T_P(i)\} R(\theta_t, c, m_t) (N_P(i) - T_P(i)) + \nu_t \cdot [F(N_{P,t}(i), a_t) - Y_t \cdot P_t(i)^{-\epsilon}] \right\}, \end{aligned}$$

$\mathbb{I}\{N > T\}$ is the indicator function, that takes a value 1 if $N > T$; this indicator function is 1 if firm i where ν_t is the Lagrange multiplier associated with the production constraints and reflects the marginal profit from producing one more item. The first-order condition with respect to $P_t(i)$ yields

$$P_t(i) = M \cdot \nu_t, \quad (6.26)$$

where $M \equiv \frac{\epsilon}{\epsilon-1}$ is the markup charged by the monopoly. First-order condition (6.26) also implies that the monopolist sets its relative price as a markup over the marginal cost of

producing one more item. The first-order condition with respect to $N_t(i)$ yields

$$\begin{aligned} \nu_t \cdot \nabla_N F(N_{P,t}(i), a_t) = & (1 - \tau_t) W_t \\ & + R(\theta_t, c, m_t) - \delta \cdot (1 - s) \cdot \mathbb{E}_t [\mathbb{I} \{N_{P,t+1}(i) > T_{P,t+1}(i)\} R(\theta_{t+1}, c, m_{t+1})]. \end{aligned}$$

The first-order condition says that firm i hires until marginal profit from hiring labor equals marginal cost. Marginal cost is the sum of recruiting costs, the wage, changes in the firm's wage from increasing employment, minus the opportunity cost of recruiting a worker in the next period.

6.6.3 Symmetric equilibrium

DEFINITION 6.6 (Government policy). A government policy is a collection of stochastic processes $\{N_{G,t}, b_{G,t}, m_t, \tau_t\}_{t=0}^{+\infty}$ that satisfy the government budget constraint (6.9) for all t and all s^t . The t element of the government policy must be measurable with respect to $(s^{t+1}, N_{-1}, b_{G,-1})$.

DEFINITION 6.7 (Price system). A price system is a collection of stochastic processes $\{W_t, Q_t(s_{t+1}|s^t)\}_{t=0}^{+\infty}$. W_t is measurable with respect to $(s^t, N_{-1}, b_{G,-1})$ and $Q_t(s_{t+1}|s^t)$ is measurable with respect to $((s^t, s_{t+1}), N_{-1}, b_{G,-1})$.

Again, I normalize $P_t = 1$ for all t .

DEFINITION 6.8 (Symmetric equilibrium). Given initial employment N_{-1} , initial government indebtedness $b_{G,-1}$, a stochastic process $\{a_t\}_{t=0}^{+\infty}$ for technology, and a stochastic process $\{i_t\}_{t=0}^{+\infty}$ for government income, a symmetric equilibrium is a feasible allocation, a government policy, and a price system that solve the household and firm problems and satisfy the wage schedule (3.7), such that for all i , $N_t(i) = N_t$ and $C_{P,t}(i) = C_{P,t}$.

A symmetric equilibrium satisfies the following conditions:

- Resource constraint:

$$\begin{aligned} a_t \cdot \{N_t - m_t \cdot [1 - (1 - s)N_{t-1}]\}^\alpha = \\ C_{P,t} + C_{G,t} + \frac{c}{\omega^2} \cdot \frac{a_t}{1 + \psi \cdot m_t} \cdot \frac{(N_t - (1 - s)N_{t-1})^2}{1 - (1 - s)N_{t-1}} \end{aligned} \quad (6.27)$$

- Wage rule:

$$W_t = a_t^\gamma \cdot w_0 \quad (6.28)$$

- Household's Euler equation:

$$Q_t(s_{t+1}|s^t) = \delta \cdot \frac{\mu_{t+1}(s^{t+1})}{\mu_t(s^t)} \cdot \left(\frac{C_{P,t+1}(s^{t+1}) + C_{G,t+1}(s^{t+1})}{C_t(s^t) + G_t(s^t)} \right)^{-\phi} \quad (6.29)$$

- Firm's Euler equation:

$$\begin{aligned} \frac{1}{M} \{ \alpha \cdot a_t (N - N_{G,t})^{\alpha-1} \} = \\ (1 - \tau_t)W_t + \mathbb{I}_t \frac{c}{\omega^2} \cdot a_t \cdot [1 + \psi \cdot m_t]^{-1} \cdot \frac{N_t - (1-s)N_{t-1}}{1 - (1-s)N_{t-1}} \\ - (1-s) \sum_{s_{t+1}} Q_t(s_{t+1}) \left[\mathbb{I}_{t+1} \frac{c}{\omega^2} [1 + \psi \cdot m_{t+1}]^{-1} \cdot a_{t+1} \cdot \frac{N_{t+1} - (1-s)N_t}{1 - (1-s)N_t} \right] \end{aligned} \quad (6.30)$$

where

$$\mathbb{I}_t \equiv \mathbb{I} \{ N_{P,t} > (1-s)N_{P,t-1} \}.$$

- Intertemporal government budget constraint:

$$\begin{aligned} b_{G,-1} + \sum_t \sum_{s^t} q_t^0(s^t) \left\{ W_t \cdot \tau_t \{ N_t - N_{G,t} \} + W_t N_{G,t} + \frac{c}{\omega^2} \cdot a_t \cdot [1 + \psi \cdot m_t]^{-1} \right. \\ \left. \cdot \frac{N_t - (1-s)N_{t-1}}{1 - (1-s)N_{t-1}} \cdot \{ N_{G,t} - (1-s)N_{G,t-1} \} \right\} = \sum_t \sum_{s^t} q_t^0(s^t) i_t \end{aligned} \quad (6.31)$$

Household's budget constraint derives from resource constraint and government's budget constraint.

6.7 Ramsey Problem

DEFINITION 6.9 (Ramsey problem). The Ramsey problem is to choose a government policy to maximize (6.1) over symmetric equilibria. A Ramsey outcome is a symmetric equilibrium that attains the maximum of (6.1).

I use the standard approach of casting the Ramsey problem in terms of constrained choice of allocations. As in Lucas and Stokey (1983), symmetric equilibria in this complete-market setup impose a single intertemporal constraint on allocation. First, total consumption $C_{P,t} + C_{G,t}$ can be expressed as a function of employment and government policies using the resource constraint (6.27)

$$C_{P,t} + C_{G,t} = \mathbb{C}(s_t, N_t, m_t, N_{t-1})$$

where

$$\begin{aligned}\mathbb{C}(s_t, N_t, m_t, N_{t-1}) &\equiv a_t \cdot \{N_t - m_t \cdot [1 - (1-s)N_{t-1}]\}^\alpha \\ &\quad - a_t [1 + \psi \cdot m_t]^{-1} \cdot \mathbb{R}(N_t, N_{t-1})\end{aligned}$$

and

$$\begin{aligned}\mathbb{O}(N_t, N_{t-1}) &\equiv \frac{c}{\omega^2} \cdot \frac{N_t - (1-s)N_{t-1}}{1 - (1-s)N_{t-1}} \\ \mathbb{R}(N_t, N_{t-1}) &\equiv \frac{c}{\omega^2} \cdot \frac{(N_t - (1-s)N_{t-1})^2}{1 - (1-s)N_{t-1}}.\end{aligned}$$

Second, (6.29) allows to express the Arrow-Debreu prices and bond prices as a function of total consumption

$$Q_t(s_{t+1}|s^t) = \delta \cdot \mu(s_{t+1}|s^t) \cdot \left(\frac{\mathbb{C}(s_{t+1}, N_{t+1}, m_{t+1}, N_t)}{\mathbb{C}(s_t, N_t, m_t, N_{t-1})} \right)^{-\phi}$$

and for $t \geq 0$, assuming $q_0^0 = 1$,

$$q_t^0(s^t) = \delta^t \cdot \mu_t(s^t) \cdot \left(\frac{\mathbb{C}(s_t, N_t, m_t, N_{t-1})}{\mathbb{C}(s_0, N_0, m_0, N_{-1})} \right)^{-\phi}. \quad (6.32)$$

Lastly, (6.30) allows to express the wage subsidy rate as a function of the allocation:

$$W_t \cdot \tau_t = \mathbb{T}(N_t, N_{t-1}, N_{t+1}, s_t, m_t, m_{t+1}, N_{G,t})$$

where

$$\begin{aligned}\mathbb{T}(N_t, N_{t-1}, N_{t+1}, s_t, m_t, m_{t+1}, N_{G,t}) &\equiv \\ &\quad - \frac{1}{M} \{ \alpha \cdot a_t (N - N_{G,t})^{\alpha-1} \} + W_t + \mathbb{I}_t \cdot a_t \cdot [1 + \psi \cdot m_t]^{-1} \cdot \mathbb{O}(N_t, N_{t-1}) \\ &\quad - (1-s)\delta \sum_{s_{t+1}} \mu(s_{t+1}|s_t) \left(\frac{\mathbb{C}(a_{t+1}, N_{t+1}, m_{t+1}, N_t)}{\mathbb{C}(a_t, N_t, m_t, N_{t-1})} \right)^{-\phi} \mathbb{I}_{t+1} \frac{a_{t+1} \cdot \mathbb{O}(N_{t+1}, N_t)}{1 + \psi \cdot m_{t+1}}.\end{aligned} \quad (6.33)$$

The government budget constraint (6.31) can now be rewritten as a function of the allocation

and government policy:

$$\begin{aligned} & \mathbb{C}(s_0, N_0, m_0, N_{-1})^{-\phi} b_{G,-1} + \sum_t \delta^t \sum_{s^t} \mu_t(s^t) \mathbb{C}(s_t, N_t, m_t, N_{t-1})^{-\phi} (\mathbb{T}(N_t, N_{t-1}, N_{t+1}, s_t, m_t, m_{t+1}, N_{G,t}) \\ & \{N_t - N_{G,t}\} + W_t N_{G,t} + a_t \cdot [1 + \psi \cdot m_t]^{-1} \cdot \mathbb{O}(N_t, N_{t-1}) \cdot \{N_{G,t} - (1 - s) N_{G,t-1}\} - i_t) = 0. \end{aligned}$$

This intertemporal budget constraint can be greatly simplified using the expression for the tax rate (6.33):

$$\begin{aligned} & \mathbb{C}(s_0, N_0, m_0, N_{-1})^{-\phi} b_{G,-1} + \sum_t \delta^t \sum_{s^t} \mu_t(s^t) \cdot \mathbb{C}(s_t, N_t, m_t, N_{t-1})^{-\phi} \\ & \left[-\frac{\alpha \cdot a_t}{M} (N_t - G_t - m_t \mathbb{U}(N_{t-1}))^\alpha + W_t \cdot N_t + \frac{a_t}{1 + \psi \cdot m_t} \mathbb{R}(N_t, N_{t-1}) - i_t \right] = 0, \quad (6.34) \end{aligned}$$

when the following transversality condition holds for any for any infinite history $s^{+\infty}$

$$\lim_{t \rightarrow +\infty} \left[\sum_{s_{t+1}} \mu_{t+1}(s^{t+1}) \mathbb{C}(a_{t+1}, N_{t+1}, m_{t+1}, N_t)^{-\phi} \mathbb{I}_{t+1} \frac{a_{t+1}}{1 + \psi \cdot m_{t+1}} \mathbb{O}(N_{t+1}, N_t) \right] (N_t - N_{G,t}) = 0,$$

where the limits are taken over sequences of histories contained in the infinite history $s^{+\infty}$.

LEMMA 6.1 (Ramsey problem). *An equivalent formulation of the Ramsey problem is to choose the collection of stochastic processes $\{N_t, N_{G,t}, m_t\}_{t=0}^{+\infty}$ to maximize*

$$\sum_t \delta^t \sum_{s^t} \mu_t(s^t) \cdot \frac{\mathbb{C}(s_t, N_t, N_{t-1}, m_t)^{1-\phi}}{1 - \phi} \quad (6.35)$$

subject to the implementability constraint (6.34), given N_{-1} and $b_{G,-1}$.

I can then recover the number of government employees in placement services:

$$m_t \cdot (1 - (1 - s) N_{t-1}),$$

the number of government employees in private firms:

$$N_{G,t} - m_t \cdot (1 - (1 - s) N_{t-1}),$$

the wage subsidy rate τ_t from (6.33), and the number of bonds issued in period T after

history s^T from the government budget constraint:

$$b_{G,T} = \sum_{t \geq T+1} \sum_{s^t} q_t^T(s^t) [i_t - \{W_t \cdot \tau_t \{N_t - N_{G,t}\} + W_t N_{G,t} \\ + \frac{c}{\omega^2} \cdot a_t \cdot [1 + \psi \cdot m_t]^{-1} \cdot \frac{N_t - (1-s)N_{t-1}}{1 - (1-s)N_{t-1}} \cdot \{N_{G,t} - (1-s)N_{G,t-1}\} \}],$$

where the Arrow Debreu prices $q_t^T(s^t)$ depend on the optimal allocation determined above through (6.32).

Clearly $G_t(s^t) = 0$ for all s^t as it only increases costs and not utility. Therefore the social planner optimizes by choosing a collection of sequence $\{N_t, m_t\}_t$. The Lagrangian of the Ramsey problem can therefore be written

$$\mathcal{L} = \mathbb{C}(s_0, N_0, m_0, N_{-1})^{-\phi} b_{G,-1} + \sum_t \delta^t \sum_{s^t} \mu_t(s^t) \cdot \mathbb{C}(s_t, N_t, m_t, N_{t-1})^{-\phi} \left(a_t \left[\frac{\alpha \cdot \mu}{M} + \frac{1}{1-\phi} \right] \right. \\ \left. \cdot (N_t - m_t \mathbb{U}(N_{t-1}))^\alpha - \mu W_t \cdot N_t - a_t \cdot \frac{\mathbb{R}(N_t, N_{t-1})}{1 + \psi \cdot m_t} \cdot \left[\mu + \frac{1}{1-\phi} \right] + \mu i_t \right). \quad (6.36)$$

6.8 Calibration

In the next sections, I use both analytical and quantitative work to study optimal unemployment-reducing policy. Before proceeding, I calibrate the policy instruments applied to my model with job rationing. In fact, I only need to calibrate one parameter : the placement-service effectiveness. To estimate the effectiveness of the placement agency (ϕ), I use a randomized experiment conducted in Sweden in 1975, and reported by Björklund and Regnér (1996). A treatment group of 216 unemployed received 7.5 hours of job search assistance each week for three months, instead of the 1.5 hours offered to the control group. Nine months after the beginning of the experiment, 48% of the treatment group and 34% of the control group were employed.

Each period, unemployed have a probability f to find a job each month. Unemployed from the treatment group have a higher probability $(1+b)f > f$ to find a job, because they receive additional job search assistance. b is the benefit from job search assistance as a fraction of normal search effort. Assuming that unemployed who find a job keep it during the nine months, 34% of the control group have found a job. Since job arrival is a Poisson process: $1 - e^{-9f} = .34$. I make two assumptions about the placement agencies. First, job search assistance has long-lasting favorable effects, because it provides unemployed with job-search techniques, training for interviews, counseling, or access to a wider network of recruiting firms. Thus, I assume for simplicity that higher search intensity in the treatment group is in effect for the nine months of the experiment. Second, I need to determine how much

resources are allocated for each hour an unemployed spend in the placement agency. Lacking more information about the experiment, I assume that a jobseeker spends half of its time with a counselor while he is in agency—he uses the resources made available by the agency the rest of the time (address books, phones, etc.). This implies that the Swedish experiment required 15 FTEs for three months to help the 216 jobseekers. Assuming that more human resources were allocated to the experiment reduces the effectiveness of placement service agencies. Assuming that the effect of placement services had shorter-lasting effects would increase the effectiveness of the agency. Therefore, these two assumptions balance each other. To conclude, 48% of the treatment group find a job after 9 months, which implies that $1 - e^{-9(1+b)f} = .48$. By assumption, the unemployed spend $(1 - z) \times 40 = 23$ hours a week searching for a job; spending 1.5 hours at the placement agency adds the equivalent of $1.5 \times 1/2 \times \phi$ hours of search; an additional 6 hours adds $6 \times 1/2 \times \phi$ hours of search; therefore, $b = \frac{6 \times 1/2 \times \phi}{23 + 1.5 \times 1/2 \times \phi}$. Solving for ϕ yields $\phi = 4.4$. To conclude, with some simplifying assumptions, I estimate $\phi = 4.4$ which means that an hour of job search assistance by a staff member of a placement agency is equivalent to adding 4.4 hours of search by a jobseeker.

6.9 Steady-State Analysis and Fiscal Multipliers

In this section, I abstract from stochastic fluctuations in technology and governmental income. I assume that $i_t = 0$ and $a_t = a$ for all t . I perform comparative static exercises to understand intuitively the policy problem faced by the government. In particular, I study how first dollar available should be spent. This is the value of the Lagrange multiplier in Ramsey problem.

In such an equilibrium, the firm must recruit some workers each period, otherwise there are no workers working in private sector. In a stationary, symmetric equilibrium, the household's Euler equation gives $Q = \delta$. I write down the steady-state Ramsey problem as constrained maximization subject to three constraints: (i) the resource constraint; (ii) the firm Euler equation, which characterizes the symmetric, decentralized equilibrium; and (iii) the per-period government budget constraint. Substituting total consumption out using the resource constraint, the steady-state Ramsey problem is to maximize

$$a \cdot N^\alpha - (1 + \psi \cdot m_t)^{-1} \frac{c \cdot a}{\omega^2} \cdot \frac{(s \cdot N)^2}{1 - (1 - s)N}$$

over $\{b_G, \tau, N_G, m\}$, subject to the firm Euler equation

$$\frac{1}{M} \{ \alpha \cdot a (N_P)^{\alpha-1} \} = (1 - \tau) \cdot W + [1 - (1 - s)\delta] (1 + \psi \cdot m)^{-1} \frac{c \cdot a}{\omega^2} \cdot \frac{s \cdot N}{1 - (1 - s)N} \quad (6.37)$$

and the government budget constraint:

$$(1 - \delta)b_G + \tau \cdot W \cdot N_P + W \cdot N_G + \frac{ca}{\omega^2} (1 + \psi \cdot m)^{-1} \cdot \frac{s \cdot N}{1 - (1 - s)N} \cdot (sN_G) = i \quad (6.38)$$

Obviously $b_G = 0$: the government issues no securities. I define $r \equiv (1 - (1 - s)\delta)$.

6.9.1 Direct employment

I assume that $m = \tau = 0$ and thus $N = N_P + G$. The Ramsey problem is

$$\max_G SW(N) = a \cdot (N)^\alpha - \frac{c \cdot a}{\omega^2} \cdot \frac{(s \cdot N)^2}{1 - (1 - s)N}$$

subject to

$$\begin{aligned} \frac{1}{M} \{ \alpha \cdot a (N - G)^{\alpha-1} \} - W - r \frac{c}{\omega^2} \frac{s \cdot N}{1 - (1 - s)N} &= 0 \quad (\lambda) \\ W \cdot G + \frac{ca}{\omega^2} \frac{s \cdot N}{1 - (1 - s)N} \cdot (s \cdot G) &= 0 \quad (\mu^G) \end{aligned}$$

The effect of first dollar on social welfare is the Lagrange multiplier μ^G . I can prove that the direct-employment multiplier is

$$\mu^G = \nabla_N SW \cdot \left(\frac{1}{W + s \cdot R(\theta, c)} \right) \cdot \left(1 - \frac{1}{1 + \frac{\alpha(1-\alpha)\omega^2}{M \cdot r \cdot c \cdot s} \cdot U^2 \cdot N^{\alpha-2}} \right). \quad (6.39)$$

The first term is the marginal effect of employment on social welfare, which is decreasing with employment because of the concavity of the social welfare function. The second term is the inverse of the per-period cost of hiring a worker, which is decreasing with technology as both recruiting costs and wages increase with technology. The last term is the marginal effect of public employment on total employment. This is 1 minus the crowding out effect of public employment on private employment. Critically, the crowding out effect is always strictly less than 1, and public jobs crowd out private jobs strictly less than one-for-one: public-job creation always reduces unemployment. In addition, the crowding-out effect increases with technology, which means that crowding-out becomes less of an issue as equilibrium unemployment rises. Figure 6.5 displays the fluctuations in direct-employment multiplier with unemployment, and breaks down the fluctuations in the multiplier.

PROPOSITION 6.1 (Direct-employment multiplier). *The amplitude of the crowding-out effect of public jobs on private jobs falls when unemployment increases; thus the multiplier μ^G for direct employment programs increases with unemployment.*

6.9.2 Wage subsidy

I assume that $N_G = 0$. Thus $N = N_P$ and the Ramsey problem is

$$\max_{\tau} SW(N) = a \cdot (N)^{\alpha} - \frac{c \cdot a}{\omega^2} \cdot \frac{(s \cdot N)^2}{1 - (1 - s)N}$$

subject to

$$\begin{aligned} \frac{1}{M} \{ \alpha \cdot a (N)^{\alpha-1} \} - (1 - \tau) \cdot W - r \frac{c}{\omega^2} \frac{s \cdot N}{1 - (1 - s)N} &= 0 \quad (\lambda) \\ \tau \cdot W \cdot N &= 0 \quad (\mu^{\tau}) \end{aligned}$$

The effect of first dollar on social welfare is the Lagrange multiplier μ^{τ} . I can prove that the wage-subsidy multiplier is

$$\mu^{\tau} = \nabla_N SW \cdot \frac{1}{\frac{c}{\omega^2} \cdot a \cdot r \cdot s \frac{N}{U^2} + \frac{\alpha \cdot (1 - \alpha)}{M} \cdot a \cdot N^{\alpha-1}}. \quad (6.40)$$

The first term is the marginal effect of employment on social welfare, which is decreasing with employment because of the concavity of the social welfare function. The second term combines the inverse of the marginal cost of a subsidy $1/(W \cdot N)$ and the marginal effect on employment of a wage subsidy. The product of these two terms is decreasing with technology. Figure 6.6 displays the fluctuations in wage-subsidy multiplier with unemployment, and breaks down the fluctuations in the multiplier.

PROPOSITION 6.2 (Wage-subsidy multiplier). *The multiplier of a wage subsidy decreases with technology. Therefore, this multiplier increases with equilibrium unemployment.*

6.9.3 Placement services

I assume that $\tau = 0$ and $G = 0$. Thus $N = N_P + m \cdot U$ and the Ramsey problem is

$$\max_m SW(N, m) = a \cdot (N(1 + m \cdot (1 - s)) - m)^{\alpha} - \frac{c \cdot a}{\omega^2 (1 + \psi \cdot m)} \cdot \frac{(s \cdot N)^2}{1 - (1 - s) \cdot N}$$

subject to

$$\begin{aligned} \frac{1}{M} \{ \alpha \cdot a (N(1 + m \cdot (1 - s)) - m)^{\alpha-1} \} - W - r \cdot (1 + \psi \cdot m)^{-1} \cdot \frac{c}{\omega} \frac{s \cdot N}{1 - (1 - s) \cdot N} &= 0 \quad (\lambda) \\ m \cdot (1 - (1 - s) \cdot N) \cdot \left[W + ca (1 + \psi \cdot m)^{-1} \frac{s \cdot N}{1 - (1 - s) \cdot N} \right] &= 0 \quad (\mu^m) \end{aligned}$$

The effect of the first dollar spent on placement services on social welfare is μ^m . I can prove that

$$\mu^m = \frac{1}{W + s \cdot R(\theta, c)} \left\{ \frac{1}{U} \nabla_m SW + \nabla_N SW \cdot \frac{1 + \left(\frac{r \cdot c \cdot M \cdot s}{\alpha \cdot (1-\alpha) \omega^2} s^{\frac{N^{2-\alpha}}{U^2}} \right) \cdot \psi \cdot N}{1 + \frac{r \cdot c \cdot M \cdot s}{\alpha \cdot (1-\alpha) \omega^2} s^{\frac{N^{2-\alpha}}{U^2}}} \right\} \quad (6.41)$$

where

$$\nabla_N SW = a\alpha N^{\alpha-1} - \frac{cs^2}{\omega^2} aN \left[\frac{1}{U^2} + \frac{1}{U} \right] \quad (6.42)$$

$$\nabla_m SW = -U \cdot a \cdot \alpha \cdot N^{\alpha-1} + \frac{c(sN)^2}{\omega^2 U} a\psi. \quad (6.43)$$

Figure 6.7 displays the fluctuations in wage-subsidy multiplier with unemployment, and breaks down the fluctuations in the multiplier. It shows clearly that the multiplier for placement services decreases sharply with unemployment. Therefore, spending a dollar on placement services is effective when unemployment is low, but not when unemployment is high.

6.9.4 Optimal mix of policies

I assume no debt in steady state: $b_{G,t} = 0$ for all t . The last step of this steady-state analysis is to determine the optimal mix of policies in steady-state, and to compare these mixes across steady-states. To do so, let me write down the Lagrangian of the Ramsey problem in steady state using the primal representation derived in Lemma 6.1. Under the assumption that $\delta = 1$, I obtain a simple representation. First, (6.37) gives the subsidy rate τ as a function of the allocation:

$$\tau \cdot W = W + s \cdot (1 + \psi \cdot m)^{-1} \frac{c \cdot a}{\omega^2} \cdot \frac{s \cdot N}{1 - (1-s) \cdot N} - \frac{1}{M} \alpha \cdot a (N - G - m \cdot \mathbb{U}(N))^{\alpha-1}.$$

Then, the government budget constraint (6.38) can be rewritten

$$W \cdot N + \frac{c \cdot a \cdot s^2}{\omega^2} (1 + \psi \cdot m)^{-1} \cdot \frac{N^2}{\mathbb{U}(N)} - \frac{1}{M} \alpha \cdot a \cdot (N - G - m \cdot \mathbb{U}(N))^\alpha = i.$$

I can write the Lagrangian as

$$\begin{aligned}\mathcal{L} = & a [N - m \cdot \mathbb{U}(N)]^\alpha - (1 + \psi \cdot m)^{-1} a \cdot c \frac{s^2}{\omega^2} \frac{N^2}{\mathbb{U}(N)} (1 + \mu) \\ & + \mu \left\{ i + \frac{1}{M} \alpha a (N - G - m \cdot \mathbb{U}(N))^\alpha - WN \right\},\end{aligned}$$

where $\mu \geq 0$ is the Lagrange multiplier and I define

$$\mathbb{U}(N) \equiv 1 - (1 - s) \cdot N.$$

The government maximizes the Lagrangian with respect to G , m , and N . τ can be backed out from the exercise. Clearly, $\nabla_G \mathcal{L} < 0$, which implies that $G^* = 0$. This is an important result. In steady state when wage subsidies are available, the government should never offer implement direct employment programs. This is because wage subsidies can achieve the exact same effect on total employment as direct employment programs, but at a strictly lower cost.

PROPOSITION 6.3 (No direct employment in steady state). *In steady-state when wage subsidies are available, for any state $s = (a, i)$, $G^*(s) = 0$. The government does not implement any direct employment programs.*

Accordingly, we only need to determine $N^*(s)$ and $m^*(s)$. Optimal policies (and the Lagrange multiplier) are determined by three equations: two first-order conditions (with respect to m and N respectively) and the one-period budget constraint

$$\begin{aligned}\left[\frac{\alpha \mu}{M} + 1 \right] \alpha (N - m \cdot \mathbb{U}(N))^{\alpha-1} & \geq \psi \frac{c}{(1 + \psi \cdot m)^2} \frac{s^2}{\omega^2} \frac{N^2}{\mathbb{U}(N)^2} (1 + \mu) \\ \left[\frac{\alpha \mu}{M} + 1 \right] \alpha (1 + m(1 - s)) (N - m \cdot \mathbb{U}(N))^{\alpha-1} & = \frac{W}{a} \mu + \frac{c}{1 + \psi \cdot m} \frac{s^2}{\omega^2} \frac{N}{\mathbb{U}(N)} \left(1 + \frac{1}{\mathbb{U}(N)} \right) (1 + \mu) \\ i + \frac{1}{M} \alpha a (N - m \cdot \mathbb{U}(N))^\alpha & = WN + a \frac{c}{1 + \psi \cdot m} \frac{s^2}{\omega^2} \frac{N^2}{\mathbb{U}(N)},\end{aligned}$$

where the first FOC holds with equality if $m > 0$.

Figure 6.8 displays the optimal mix of wage subsidy and placement service for different steady states in the calibrated model. Figure 6.9 displays the effect of these labor market policies on unemployment. In this simulation exercise, $i = 0.5\%$: roughly speaking, the government can spend 0.5% of GDP on active labor market policies. In this steady-state analysis, it appears clearly that the optimal mix of active labor market policies varies with the state of the labor market. On the one hand, when technology is low and unemployment high it is optimal to subsidize wages and not invest in placement services. On the other

hand, when technology is high and unemployment low it is optimal to reduce wage subsidies and invest increasingly in placement services (in the sense that the number of placement officers per unemployed worker should increase).

The intuition for these results is twofold. First, in bad times firm's recruiting costs are low, and placement services barely reduce these costs further. Accordingly, private employment does not increase much when placement services are implemented. In good times however, the labor market is tight and recruiting costs are high, such that placement services allow to reduce the marginal costs faced by firms, and increase private employment, significantly. Second, from a social welfare perspective the amount of resources spent on recruiting is low in bad times and high in good times; therefore allocating resources to placement services is more effective in good times.

6.9.5 Optimal mix of policies when wage subsidies are not available

I maintain the assumption that $\delta = 1$ and thus $r = s$. I now assume that $\tau = 0$: wage subsidies are not available to the government. The firm's Euler equation now becomes

$$\frac{1}{M} \alpha \cdot a (N - N_G)^{\alpha-1} = W + s (1 + \psi \cdot m)^{-1} \frac{c \cdot a}{\omega^2} \cdot \frac{s \cdot N}{\mathbb{U}(N)}$$

which allows me to express the policy variable m as a function of total employment N and public employment N_G :

$$\begin{aligned} \frac{c \cdot a \cdot s^2}{\omega^2} (1 + \psi \cdot m)^{-1} &= \left\{ \frac{1}{M} \alpha \cdot a (N - N_G)^{\alpha-1} - W \right\} \cdot \frac{\mathbb{U}(N)}{N} \\ m &= \frac{1}{\psi} \left[\frac{c \cdot a \cdot s^2}{\omega^2} \frac{N}{\mathbb{U}(N)} \left\{ \frac{1}{M} \alpha \cdot a (N - N_G)^{\alpha-1} - W \right\}^{-1} - 1 \right]. \end{aligned}$$

This result in turn simplifies the government budget constraint (6.38) to

$$\frac{1}{M} \alpha \cdot a (N - N_G)^{\alpha-1} \cdot N_G = i.$$

I can now solve this optimization program over N, N_G , and recover the optimal policies m^*, G^* . Figure 6.10 displays the optimal mix of policies when wage subsidies are not available. This figure shows very clearly that at low unemployment rates, the government should implement solely placement services. On the other hand, at high initial unemployment rate, the government should implement only direct employment programs. With this calibration, the transition from one policy regime to the other occurs in the 7%–9% range.

6.10 Steady-State Comparison with Other Models

6.10.1 MP model

Equation (4.7) from Chapter 4 in steady state

$$1 - \beta = [1 - \delta \cdot (1 - s)] \cdot \frac{c}{q(\theta)} + c \cdot (1 - s) \cdot \delta \beta \theta. \quad (6.44)$$

This equation can be compared with the second-best allocation described in (6.22) with $\alpha = 1$, reported here again for convenience:

$$(1 - \eta) = [1 - \delta \cdot (1 - s)] \frac{c}{q(\theta)} + \delta \cdot (1 - s) \cdot c \cdot \eta \cdot \theta. \quad (6.45)$$

Comparing these equations, it is clear that the equilibrium in the decentralized economy of the MP model achieves the second best, on condition that workers' bargaining power equals the unemployment-elasticity of the matching function:

$$\beta = \eta.$$

This result was first proven by Hosios (1990). In this case, equilibrium unemployment is always efficient, and no policy interventions are needed in the MP model. Even if this assumption did not hold, unemployment would be either always too high (if $\beta > \eta$), or always too low (if $\beta < \eta$). The model would not have recessions: there would be no periods when unemployment departs largely from its efficient level. Therefore, there is no need for cyclical unemployment-reducing policies in the MP model. Moreover, when the optimality condition is not respected, welfare cost of unemployment are small as displayed on Table 6.A.

6.10.2 MPS model

The MPS model differs from the MP model because it has rigid wages. Real wage rigidity creates distortions, and equilibrium unemployment departs from second-best unemployment, especially during recessions. It is interesting to study how the policy multipliers behave in this model. These multipliers are directly obtained from those derived in Section 6.9 by plugging in $\alpha = 1$.

Direct employment. In the MPS model, the direct-employment multiplier given by (6.39) becomes $\mu^G = 0$ because the crowding out effect of public jobs on private jobs

$$\left[1 + \frac{\alpha \cdot (1 - \alpha) \omega^2}{M \cdot r \cdot c \cdot s} \cdot U^2 \cdot N^{\alpha-2} \right]^{-1}$$

is always 1 when $\alpha = 1$. Accordingly, direct-employment programs have no effect on unemployment in the MPS model, because public jobs crowd out private jobs one for one. Intuitively since unemployment is due to matching frictions and not to a lack of jobs, creating public jobs directly has no effect on aggregate unemployment: it simply replaces private jobs one-for-one with public jobs. Figure 6.12 illustrates this result in a calibrated MPS model.

Wage subsidy. The placement-service multiplier given by (6.40) becomes

$$\mu^r = \nabla_N SW \cdot \left[\frac{c}{\omega^2} \cdot a \cdot r \cdot s \frac{N}{U^2} \right]^{-1}. \quad (6.46)$$

For the same (N, U) point, this multiplier is strictly larger in the MPS model. Therefore wage subsidies have an even larger effect in the model without job rationing, as clearly illustrated on Figure 6.13.

Placement services. The placement-service multiplier given by (6.41) becomes

$$\mu^m = \frac{1}{W + s \cdot R(\theta, c)} \left\{ \frac{1}{U} \nabla_m SW + \nabla_N SW \cdot \psi \cdot N \right\}. \quad (6.47)$$

In a calibrated model, the placement-service multiplier is roughly constant over the business cycle. As shown on Figure 6.14, the placement-service multiplier barely falls when unemployment increases. Therefore, in the MPS model, the absence of job rationing implies that improving matching is an effective way to reduce unemployment, increase output, and increase social welfare whatever the state of the labor market is.

Optimal mix of policies. Again, since direct employment has no effect on unemployment, the social planner only resorts to placement services and wage subsidies. Accordingly, we only need to determine $N^*(a)$ and $m^*(a)$. Optimal policies (and the Lagrange multiplier) are determined by three equations: two first-order conditions (with respect to m and N respectively) and the one-period budget constraint. In the MPS model, we get

$$\begin{aligned} [\mu + 1] &\geq \psi (1 + \psi \cdot m)^{-2} c \frac{s^2}{\omega^2} \frac{N^2}{\mathbb{U}(N)^2} (1 + \mu) \\ [\mu + 1] (1 + m(1 - s)) &= \frac{W}{a} \mu + (1 + \psi \cdot m)^{-1} c \frac{s^2}{\omega^2} \frac{N}{\mathbb{U}(N)} \left(1 + \frac{1}{\mathbb{U}(N)} \right) (1 + \mu) \\ i + a(N - m \cdot \mathbb{U}(N)) &= WN + (1 + \psi \cdot m)^{-1} ac \frac{s^2}{\omega^2} \frac{N^2}{\mathbb{U}(N)}, \end{aligned}$$

where the first FOC holds with equality if $m > 0$.

Figure 6.15 displays the optimal mix of wage subsidy and placement service for different steady states in the calibrated model. Figure 6.16 displays the effect of these labor market policies on unemployment. In this simulation exercise, $i = 0.5\%$: roughly speaking, the government can spend 0.5% of GDP on active labor market policies. In this steady-state analysis, it appears clearly that the optimal mix of active labor market policies varies with the state of the labor market. On the one hand, when technology is low and unemployment high it is optimal to subsidize wages and not invest in placement services. On the other hand, when technology is high and unemployment low it is optimal to reduce wage subsidies and invest increasingly in placement services (in the sense that the number of placement officers per unemployed worker should increase). Comparing the optimal mix of policies in a model with job rationing (Figure 6.8) to that in a model without job rationing (Figure 6.15), it is obvious that placement services are more effective in the model without job rationing, because they are used in larger proportion in the model without job rationing.

6.11 Concluding Remarks

This chapter derived the second-best allocation of the economy with job rationing and matching frictions presented in Chapter 5. Comparing this socially optimal allocation to the equilibrium allocation in the decentralized economy, I find that the welfare cost of unemployment is large, about 3% of output on average. Unemployment is not at a socially optimal level in the decentralized economy because firms have monopoly power, and because wages do not respond to labor market tightness. Unemployment is especially above the socially optimal level in recessions, because wages are rigid and are especially high in recessions.

This quantitative result suggest that large welfare gains may be achieved if the government implements unemployment-reducing labor market policies. I then derive the optimal mix of policies when the government can choose dynamically from three unemployment-reducing policies: direct employment, placement services, and a wage subsidy. I find that the optimal unemployment-reducing policy evolve over the business cycle: its puts more weight in good times than in bad times on policy instruments reducing matching frictions, such as placement services; conversely, it puts more weight in bad times than in good times on policy instruments creating jobs directly, such as direct employment programs and wage subsidies.

These results differ starkly from those obtained in existing search-and-matching in which job rationing is absent. In these models, improving matching remains effective even when unemployment is high. Moreover, direct employment programs have no effect on unemployment in equilibrium, because public jobs crowd out private jobs one-for-one.

This chapter characterized the optimal mix of unemployment-reducing policies in a continuum of steady states. Future research should numerically solve the Ramsey problem in a

stochastic environment in order to compute the optimal history-contingent schedule of labor market policies. As for monetary policy, it may even be possible to find simple policy rules that closely approximate the optimal dynamic policy.

Appendix 6.A Tables and Graphs

	U	V	θ	Y	a
Standard Deviation	0.010 (0.002)	0.011 (0.002)	0.021 (0.003)	0.019 (0.002)	0.019 (0.002)
Autocorrelation	0.824 (0.056)	0.727 (0.099)	0.788 (0.073)	0.845 (0.037)	0.844 (0.037)
Correlation	1	-0.958 (0.023)	-0.988 (0.007)	-0.794 (0.058)	-0.790 (0.059)
	—	1	0.991 (0.005)	0.754 (0.068)	0.751 (0.069)
	—	—	1	0.781 (0.061)	0.778 (0.062)
	—	—	—	1	1.000 (0.000)
	—	—	—	—	1
	—	—	—	—	—

Table 6.1: Simulated moments of second-best allocation. Results from simulating the second-best policy function with stochastic productivity. All variables are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 6.5 provides details on the simulation. The policy function was obtained by solving the social planner's dynamic program using value function iteration.

u	Technology			Welfare loss		
	MP	MP ^{<i>l</i>}	MP ^{<i>h</i>}	MP	MP ^{<i>l</i>}	MP ^{<i>h</i>}
3.8 %	1.18	1.06	1.54	0.0 %	0.2 %	0.5 %
5.3 %	1.00	1.00	1.00	0.0 %	0.2 %	0.5 %
6.3 %	0.95	0.98	0.84	0.0 %	0.1 %	0.5 %
7.8 %	0.90	0.96	0.70	0.0 %	0.1 %	0.5 %
9.4 %	0.87	0.95	0.62	0.0 %	0.1 %	0.4 %
10.8 %	0.86	0.95	0.58	0.0 %	0.1 %	0.4 %
14.0 %	0.84	0.94	0.53	0.0 %	0.0 %	0.3 %

Table 6.2: Cost of unemployment in the MP model (as percentage of second-best social welfare). The MP model is calibrated with a bargaining power $\beta = 0.5$. MP^{*l*} is the MP model with a low bargaining power for workers $\beta = 0.25$, and MP^{*h*} is the MP model with a high bargaining power $\beta = 0.75$. In the MP^{*l*} and MP^{*h*} models, home production z is calibrated so that the models match the average unemployment $u = 5.3\%$ for the average labor productivity $a = 1$. This yields $z = 0.7$ in the MP model, $z = 0.93$ in the MP^{*l*} model and $z = 0.45$ in the MP^{*h*} model. The unemployment rates are from the seasonally-adjusted monthly series constructed by the Bureau of Labor Statistics (BLS) from the Current Population Survey (CPS). 5.3% is the average unemployment rate for the period December 2000–January 2009. The driving forces for these models are computed so that a variant of (6.44) including home production holds at these unemployment rates. Second-best allocation (θ^*, u^*) is derived from a variant of (6.45) including home production. Then, welfare losses at these unemployment rates are computed.

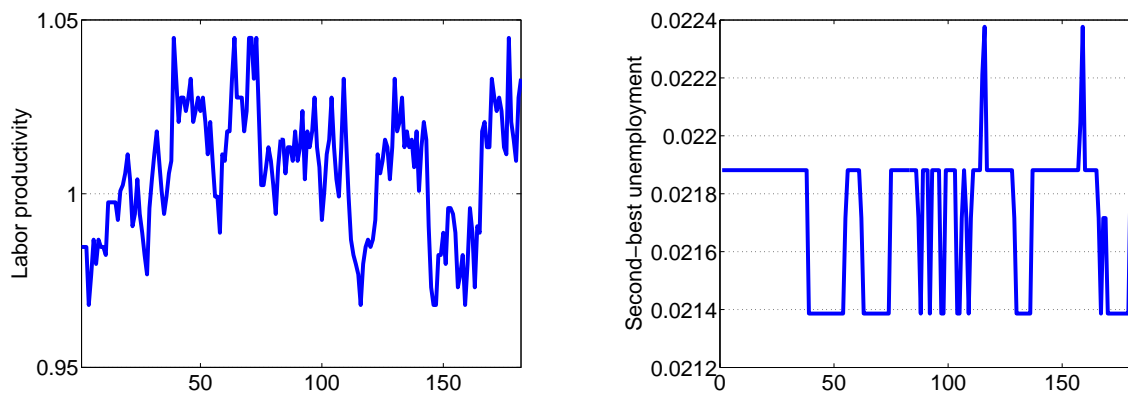


Figure 6.1: Simulated labor productivity, and second-best unemployment. The top graph is simulated quarterly labor productivity. The bottom graph is the corresponding simulated second-best unemployment. The construction of second-best unemployment is detailed in Section 6.5. Sample size is 182 quarters.

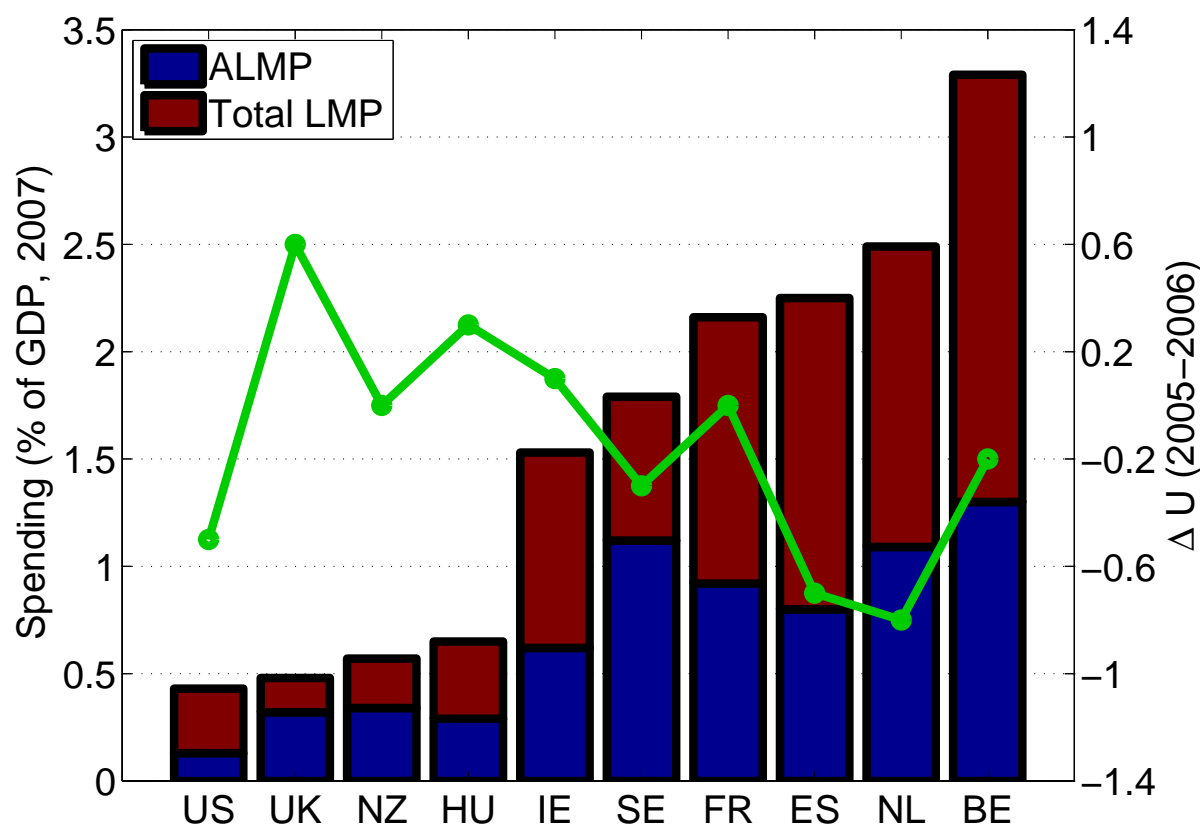


Figure 6.2: Spending on active labor market policies (ALMP) and labor market policies (LMP) in a sample of OECD countries in 2007. This graph also reports the change in unemployment between 2005 and 2006 in each country, to crudely proxy for the position of each national labor market in the business cycle. A high ΔU signals that the country entered a recession, and a low ΔU that the country entered an expansion.

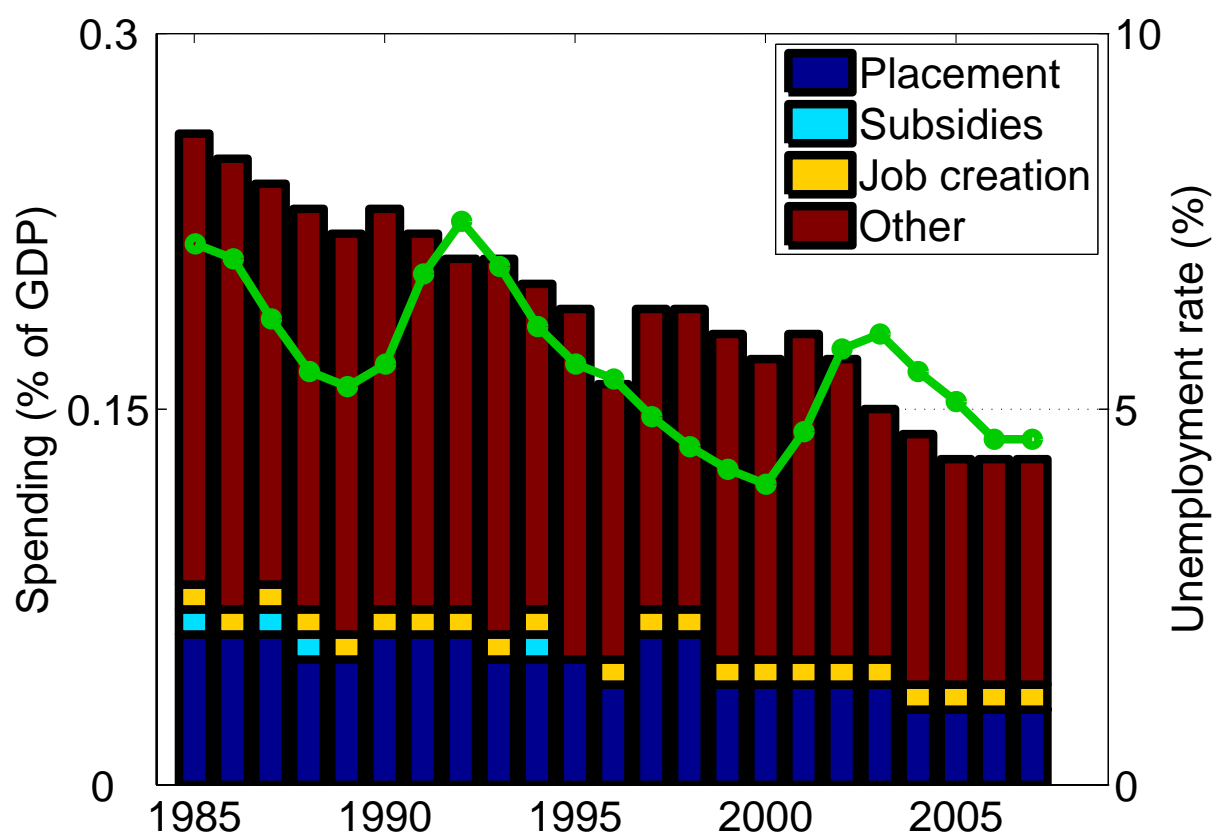


Figure 6.3: Spending on different active labor market policies in the U.S., 1985–2007, and national unemployment rate. Data collected by the OECD.

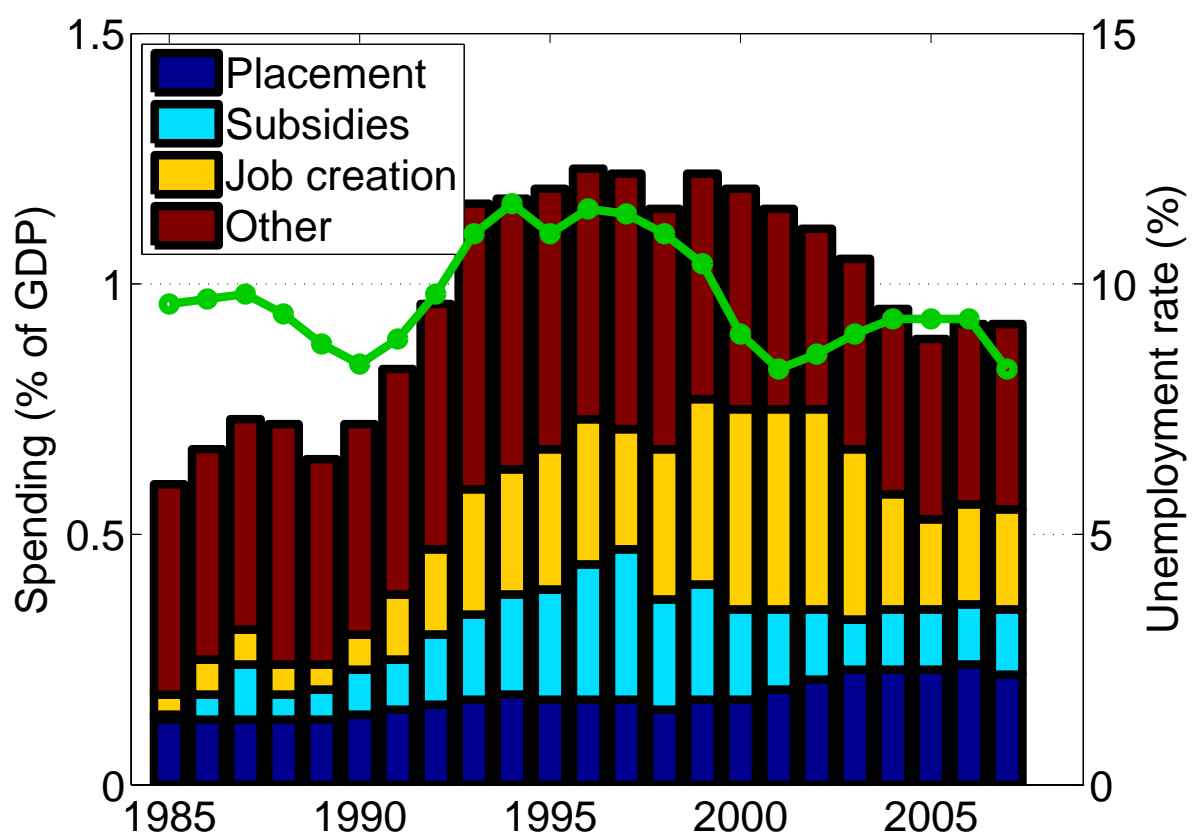


Figure 6.4: Spending on different active labor market policies in France, 1985–2007, and national unemployment rate. Data collected by the OECD.

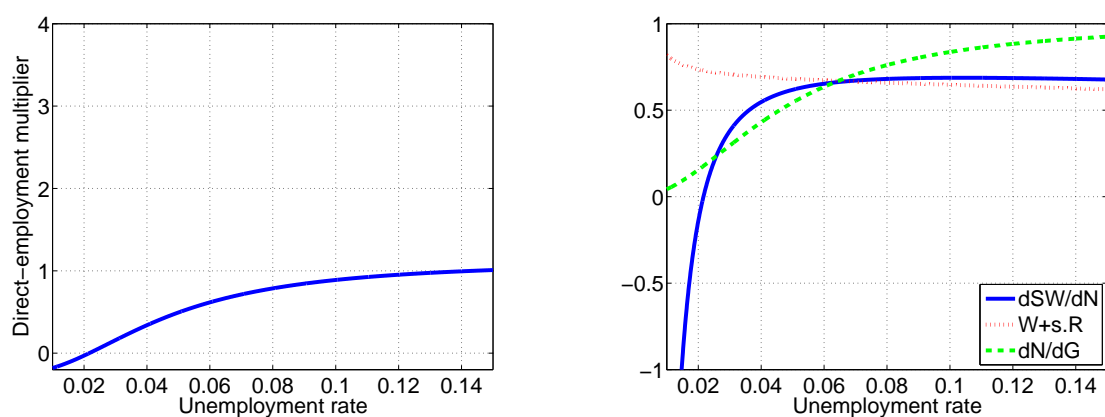


Figure 6.5: Direct-employment multiplier in calibrated model with job rationing (right plot). Decomposition of the fluctuations in the direct-employment multiplier in calibrated model with job rationing (left plot). The direct-employment multiplier represents the increase in social welfare achieved by spending one dollar on direct employment programs. I compute this multiplier from (6.39).

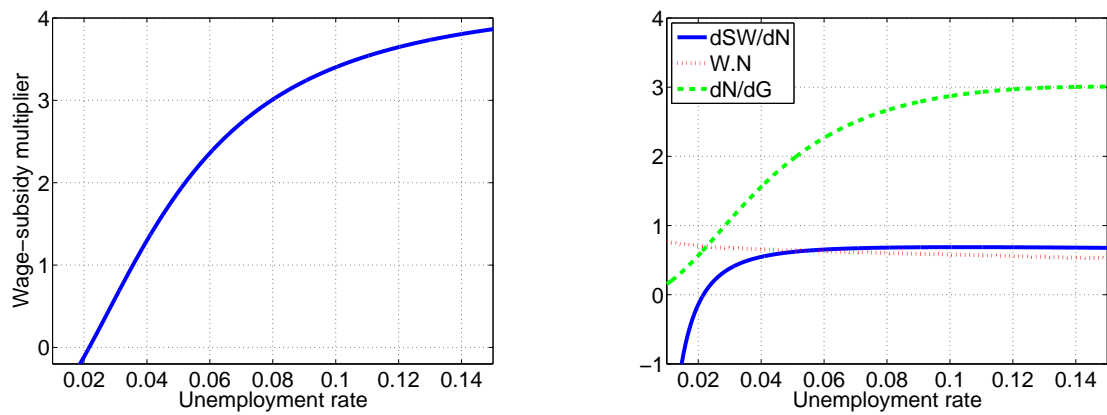


Figure 6.6: Wage-subsidy multiplier in calibrated model with job rationing (right plot). Decomposition of the fluctuations in wage-subsidy multiplier in calibrated model with job rationing (left plot). The wage-subsidy multiplier represents the increase in social welfare achieved by spending one dollar on a wage subsidy. I compute this multiplier from (6.40).

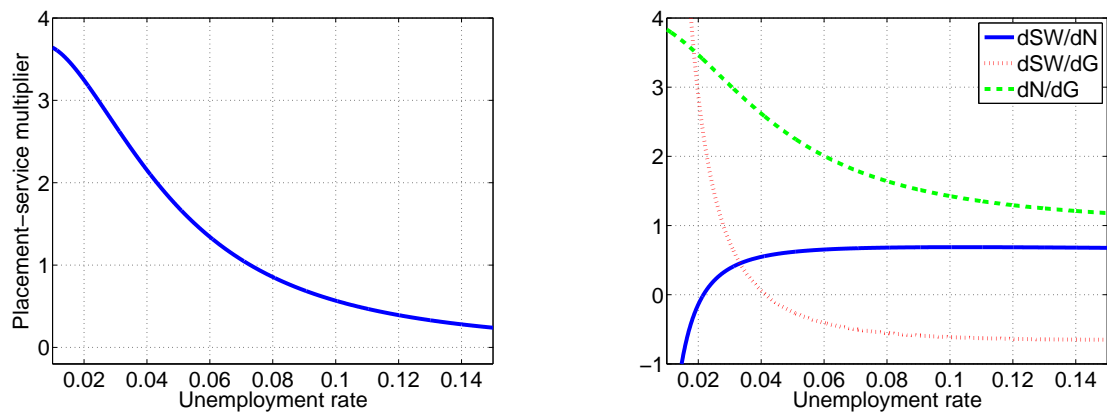


Figure 6.7: Placement-service multiplier in calibrated model with job rationing (right plot). Decomposition of the fluctuations in placement-service multiplier in calibrated model with job rationing (left plot). The placement-service multiplier represents the increase in social welfare achieved by spending one dollar on placement services. I compute this multiplier from (6.41).

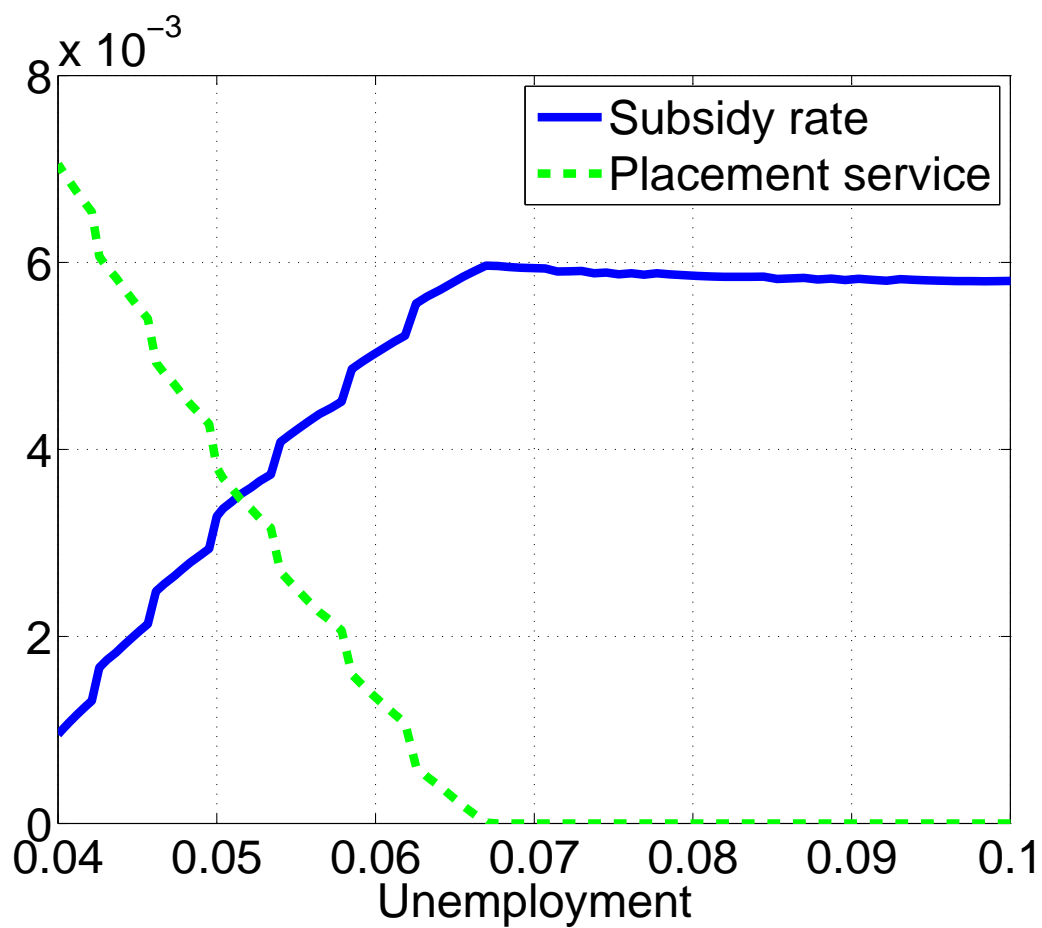


Figure 6.8: Optimal mix of active labor market policies in steady state, in a calibrated model with job rationing.

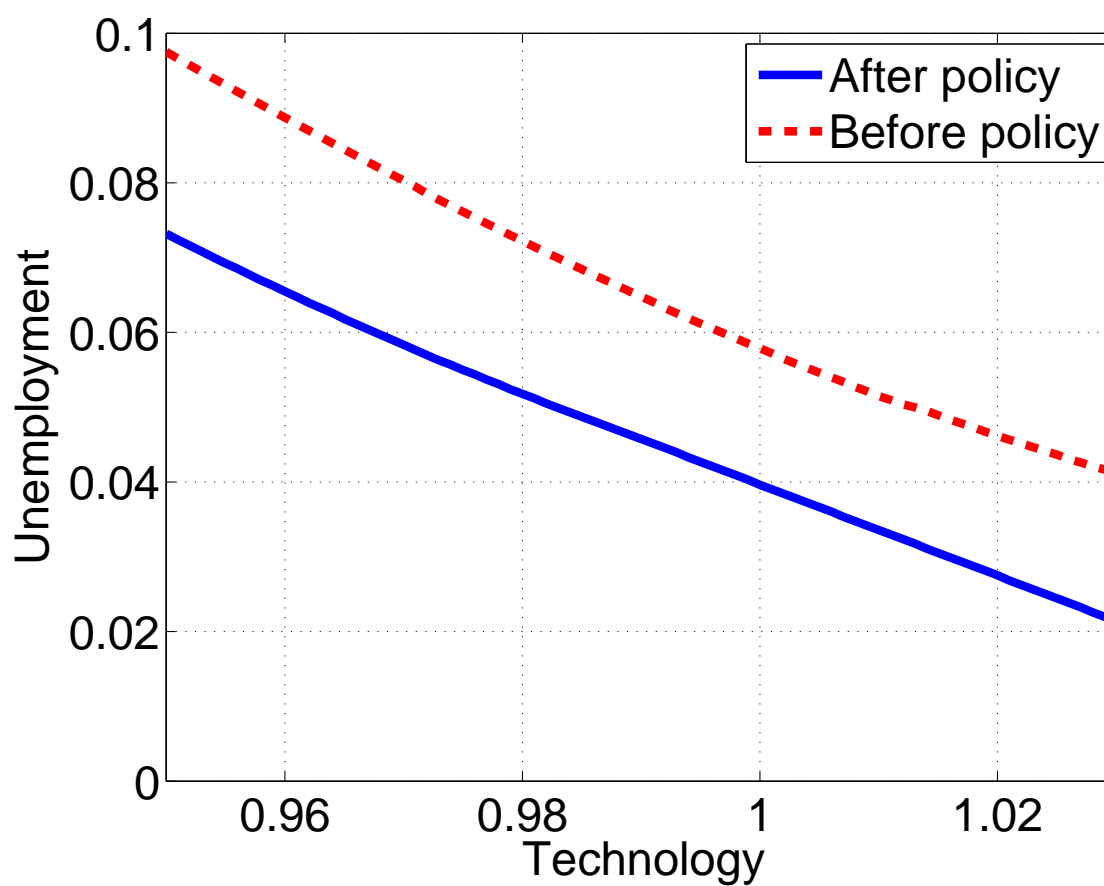


Figure 6.9: Optimal level of unemployment after policy intervention, compared with the actual level of unemployment before policy intervention. The policy experiment is conducted in the calibrated model with job rationing.

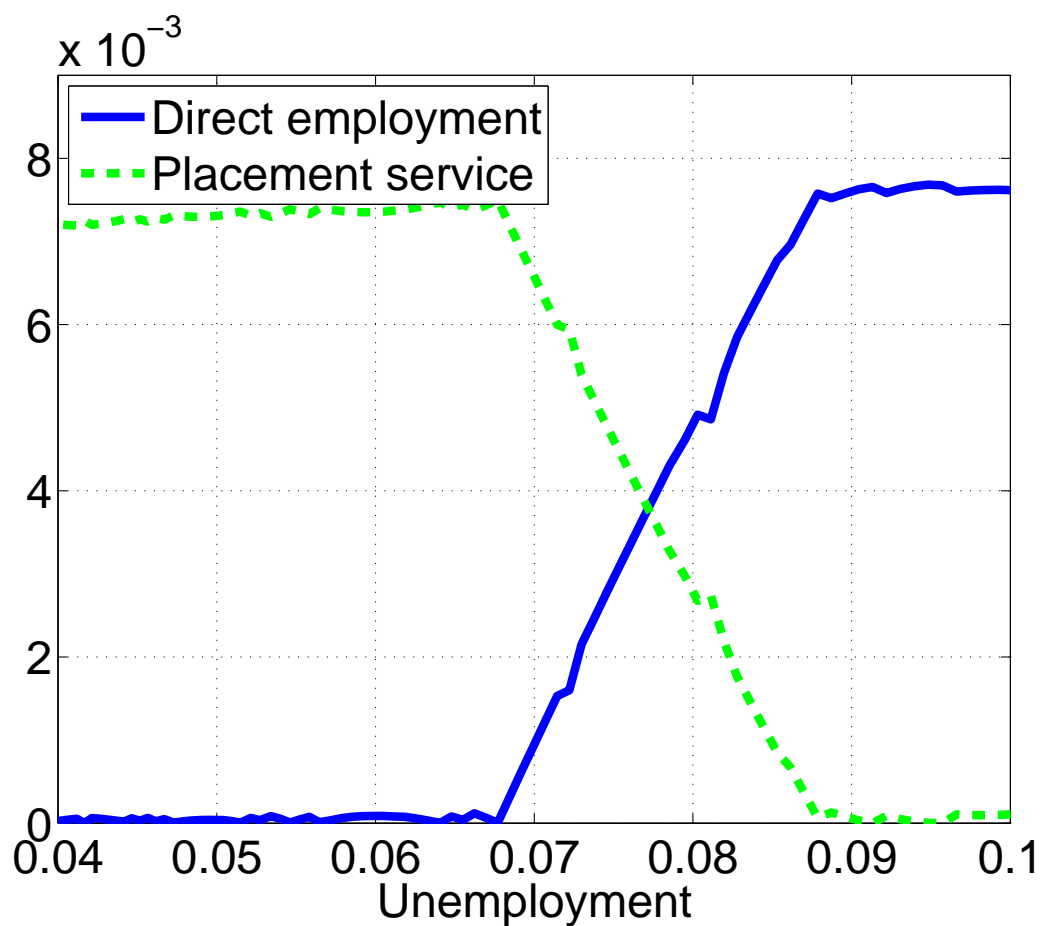


Figure 6.10: Optimal mix of active labor market policies in steady state, in the calibrated model with job rationing. In this situation, wage subsidies are not available and the government chooses between direct employment and placement services.

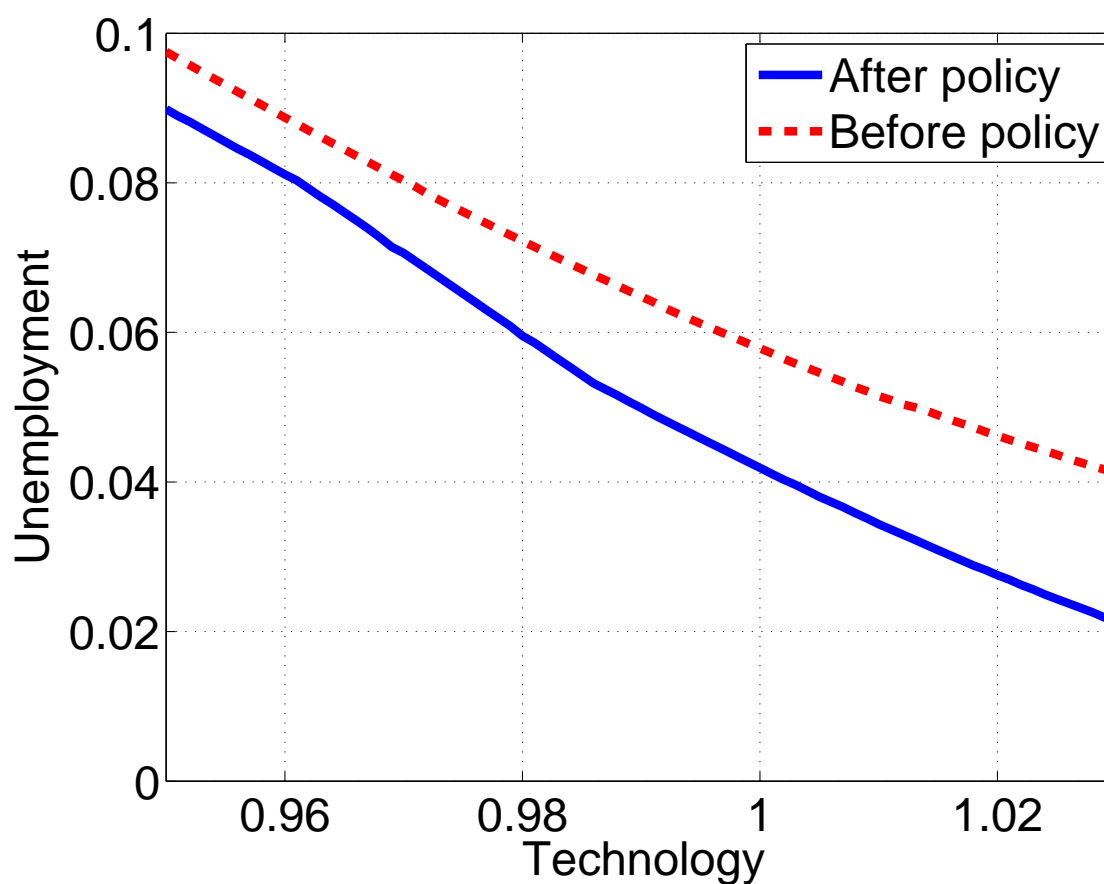


Figure 6.11: Optimal level of unemployment after policy intervention, compared with the actual level of unemployment before policy intervention. The policy experiment is conducted in the model with job rationing. Wage subsidies are not available.

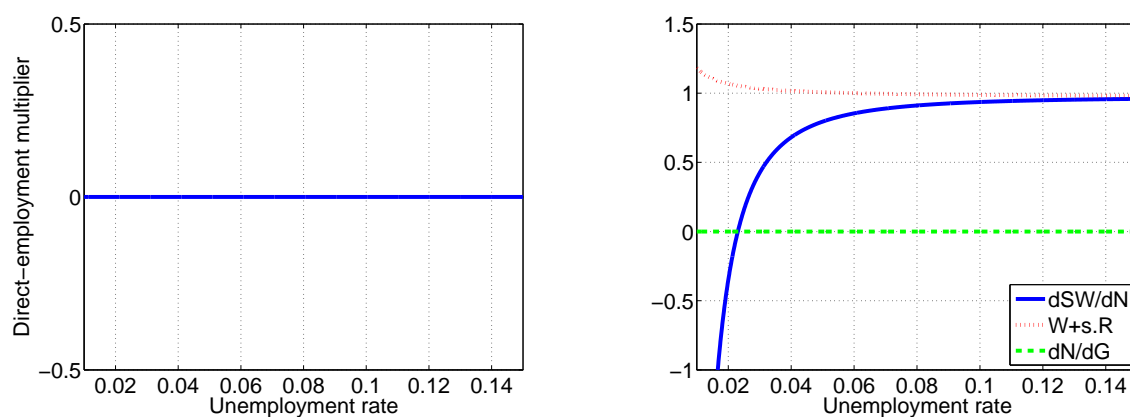


Figure 6.12: Direct-employment multiplier in the calibrated MPS model, which does not have job rationing (right plot), and the decomposition of the fluctuations in direct-employment multiplier in calibrated model with job rationing (left plot). The direct-employment multiplier represents the increase in social welfare achieved by spending one dollar on direct employment programs.

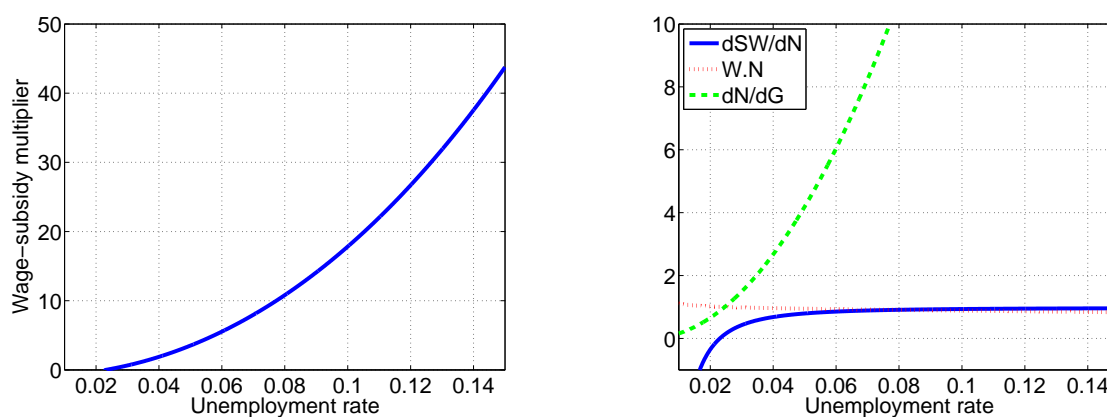


Figure 6.13: Wage-subsidy multiplier in calibrated model with job rationing (right plot), and the decomposition of the fluctuations in wage-subsidy multiplier (left plot). The wage-subsidy multiplier represents the increase in social welfare achieved by spending one dollar on a wage subsidy. I compute this multiplier from (6.46).

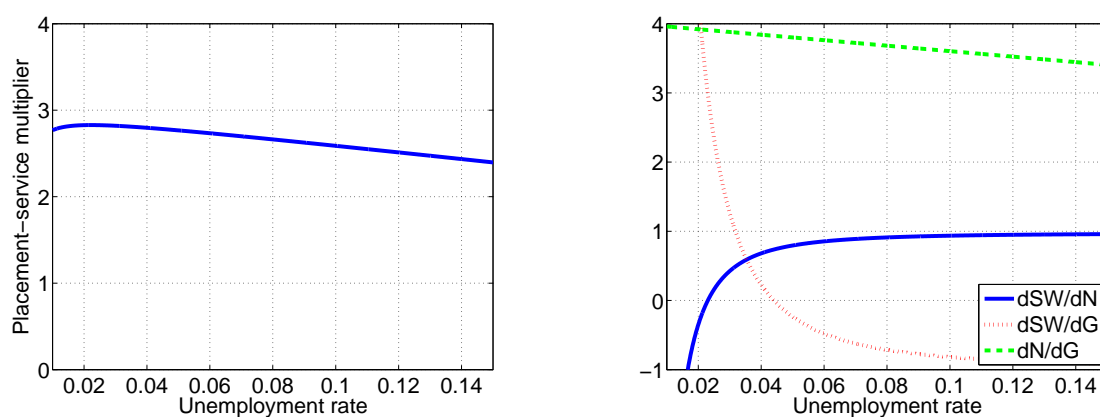


Figure 6.14: Placement-service multiplier in the calibrated MPS model, which does not have job rationing (right plot), and the decomposition of the fluctuations in placement-service multiplier in calibrated model with job rationing (left plot). The placement-service multiplier represents the increase in social welfare achieved by spending one dollar on placement services. I compute this multiplier from (6.47).

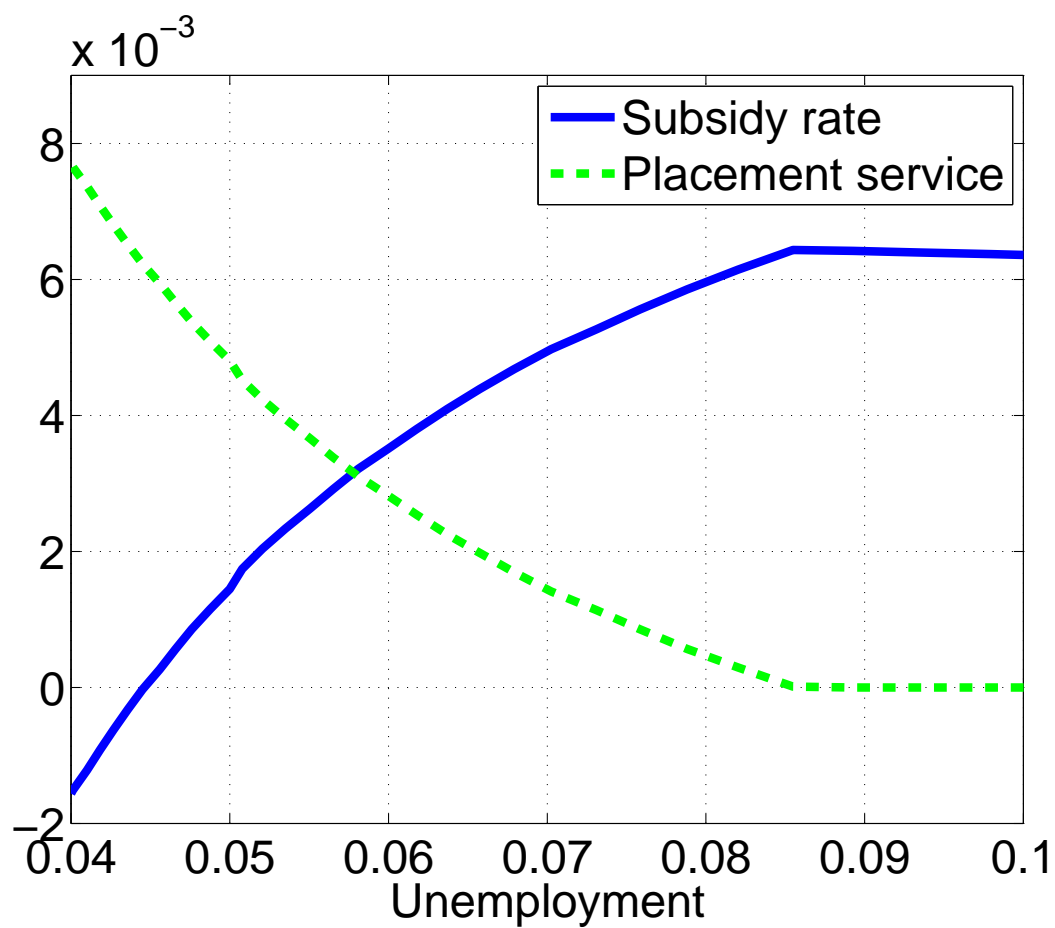


Figure 6.15: Optimal mix of active labor market policies in steady state, in the calibrated MPS model. In the MPS model, there is no job rationing.

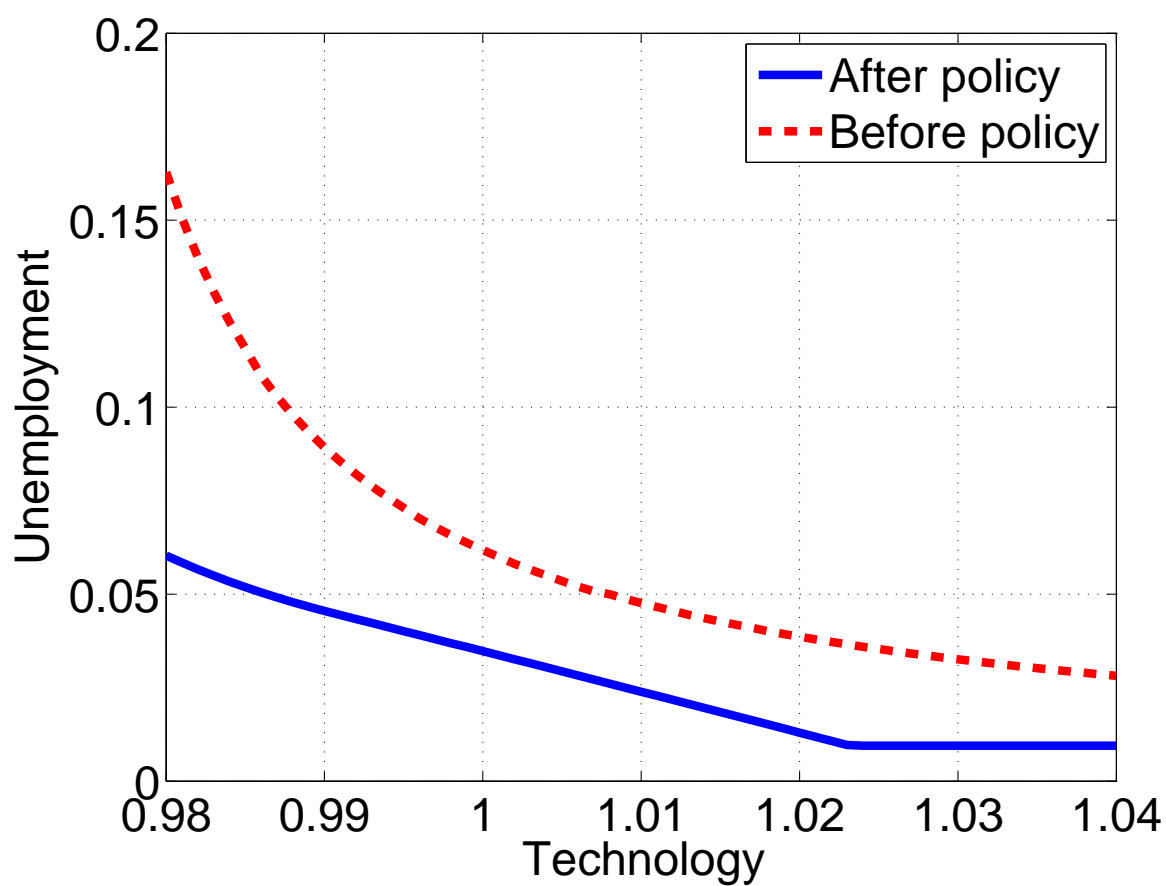


Figure 6.16: Optimal level of unemployment after policy intervention, compared with the actual level of unemployment before policy intervention. The policy experiment is conducted in the MPS model, in which there is no job rationing.

Chapter 7

Conclusion, and Directions for Future Research

7.1 Summary

By modeling unemployment as the result of matching frictions and job rationing, this dissertation develops a tractable, general model of the labor market in which unemployment can be decomposed as the sum of rationing unemployment—reflecting a shortage of jobs in the economy— and frictional unemployment—reflecting the existence of matching frictions in the labor market.

By studying these two components of unemployment, I derive three main results. First, I show theoretically in Chapter 3 that (i) in expansions matching frictions explain all of unemployment whereas (ii) in recessions, job rationing generates most of unemployment and matching frictions contribute little to unemployment. Second, in Chapter 5, I construct historical time series for frictional unemployment and rationing unemployment in a model of the labor market calibrated with U.S. data. I find that the degree of wage rigidity and diminishing marginal returns to labor observed in the data predict some rationing unemployment in the average state, and generate fluctuations in rationing unemployment that are more than twice as large as those of total and frictional unemployment. In the model calibrated with U.S. data, I find that when unemployment is below 5%, it is only frictional; but when unemployment reaches 9%, frictional unemployment amounts to less than 2% of the labor force, and rationing unemployment to more than 7%.

Third, in Chapter 6, I study the normative implications of these positive results to find that unemployment-reducing policies can improve welfare significantly, and that optimal policies should be adapted to the state of the labor market. In particular, the government should place more emphasis on reducing frictions in good times, and on creating jobs in bad times.

To conclude, the model studied in this dissertation offers an improvement over the current

unemployment literature by bringing together two source of unemployment (and two strands of research) into one single framework. It presents many promising avenues that will develop our theoretical understanding of the causes of unemployment, and also offer novel policy insights. However, this dissertation is only a first attempt at providing a unified framework to study unemployment, and it has limitations that will have to be addressed in future research. This chapter concludes the dissertation by highlighting important directions for future research, their possible impact on the results presented in this work, as well as ongoing research efforts in these directions.

7.2 Testing the Job-Rationing Hypothesis

This dissertation shows how the introduction of job rationing in a standard search-and-matching model modifies our understanding of unemployment fluctuations. An important next step is to test whether we can reject models without job rationing using empirical data. Below, I suggest three possible answers to this question.

7.2.1 Comparison of simulated moments across models

A simple method to test the job-rationing hypothesis is to compare the simulated moments of a calibrated model with job rationing, to those of a similar model without job rationing. For instance, it is natural to compare the simulated moments of the model with job rationing presented in Chapter 5, to those of the benchmark search-and-matching models presented in Chapter 4. Appendix 7.A calibrates the MP model (presented in Section 4.2), the MPS model (presented in Section 4.3), and the SZ model (presented in Section 4.4). The calibration parameters are summarized in Table 7.B.

Table 7.2 summarizes the key moments of interest estimated in U.S. data, and simulated in the job-rationing model, and in the three benchmark models without job rationing. I focus on the standard deviations of unemployment rate and labor market tightness, since they reflect the ability of models to amplify shocks and there is a prolific literature focusing especially on these moments (for example, Shimer 2005, Hall 2005a, Hagedorn and Manovskii 2008, Hall and Milgrom 2008). It is clear that models without job rationing do not match empirical evidence as well the model with job rationing.

In the MPS model with $\gamma = 0$, a high degree of wage rigidity produces too much amplification. The technology-elasticity of labor market tightness is $0.809 \times 4.708 / 0.018 = 211$, which is more than 20 times the elasticity observed in U.S. data. In the MPS model with $\gamma = 0.7$, wages are as flexible as in my model. But the gross marginal profit is extremely small because firms are perfectly competitive, and it is independent of employment. Thus, a small shock to technology is much more amplified in the MPS model with $\gamma = 0.7$ than in the job-rationing model. To reduce amplification in the MPS model the elasticity of wages with

respect to technology should be even higher, which seems implausible empirically. Indeed, Haefke et al. (2008) obtain an elasticity of 0.7 without controlling on composition effects for jobs created in recessions versus booms. As argued earlier in the dissertation, there are obvious composition effects among jobs newly created over the business cycle, which are difficult to control for. For instance, workers may accept lower-paid jobs in recessions and move to better jobs during expansions, which would bias upwards their estimate of wage rigidity for a given job. Martins et al. (2009) suggest using Portuguese data that once these effects are taken into account, the estimated wage rigidity is more important (the elasticity is lower). On the other hand, my model with job rationing matches the empirical moments well even with a technology-elasticity of wages of 0.7, because the introduction of diminishing marginal returns to labor reduces the volatility of unemployment. The intuition is simple: after a negative technology shock, firms reduce employment, which increases marginal productivity through diminishing returns. Therefore, smaller movement in employment are sufficient to bring back the marginal revenue product of labor at the level of marginal costs.

In the MP and SZ models technology shocks are not sufficiently amplified. As highlighted by Shimer (2005), the elasticity of labor market tightness with respect to technology is close to 1 ($0.975 \times 0.018 / 0.018 \approx 1$). In the general equilibrium model presented in Chapter 3, the value to the household of having a member unemployed is nil: unemployed workers search for jobs, and they neither have time for leisure nor for home production; moreover, I abstract from any intervention by the government, so that there is no unemployment insurance. Since unemployment is a costly experience, bargained wages are low except if workers have a lot of bargaining power. In practice, targeting a steady-state unemployment rate of 5.8% requires setting a high bargaining power in both models. Therefore, wages in the calibrated model are very flexible, and labor market variables are very stable. To increase the amplification of technology shocks, the value of unemployment must be increased—unemployment should be a more pleasant experience.¹ However, this assumption contradicts empirical evidence that shows that a spell of unemployment has a large and long-lasting negative impact on future health and professional outcomes (for example, von Wachter et al. 2007, Sullivan and von Wachter 2009).

To summarize, a job-rationing model performs at least as well as the benchmark model from the search-and-matching literature. The combination of wage rigidity and diminishing marginal returns to labor seem to improve the empirical fit of the model. This evidence is however only suggestive. The set of moments examined is very small, and most parameters cannot be calibrated very precisely. These models are a very crude representation of the reality, which makes statistical tests difficult to implement. Given these limitations, the preliminary results should be confirmed using other methods.

¹For instance, Hagedorn and Manovskii (2008) show that the canonical MP model matches empirical moments if the value of time of an unemployed worker is 95.5% that of an employed worker.

7.2.2 Temporary layoffs

Another piece of evidence in favor of the importance of job rationing is the existence of temporary layoffs. Workers on temporary layoffs remain attached to the firm, and are available for recall by the firm without the need to post a vacancy.² As first emphasized in a series of paper by Martin Feldstein (for example, Feldstein 1975, Feldstein 1976, Feldstein 1978), many laid off workers in manufacturing are eventually recalled. Feldstein (1975) shows, using establishment-level data from the BLS for manufacturing in 1960-1975, that an average of 1.6% of all employees are laid-off each month, while 1.3% of all employees are rehired. The ratio of rehires to layoffs, which represents the fraction of workers who are laid off and then rehired, is 85% on average. It never falls below 70%. Lilien (1980) re-examines the same data and shows that the fraction of workers who are laid off and eventually rehired is above 70%. Both studies also show that temporary layoffs are strongly procyclical. If these manufacturing firms have to wait to rehire these workers, which they could do immediately at no cost, it must be that opening more jobs would be temporarily unprofitable. Jobs are temporarily rationed.

What is more, the phenomenon of temporary layoffs is not limited to manufacturing. Among job losers, the CPS survey lists persons on temporary layoff, who have been given a date to return to work or who expect to return within 6 months (persons on layoff need not be looking for work to qualify as unemployed. Figure 7.1 displays the evolution of this time series in the US for 1967-2009. On average, workers on temporary layoff represent 14% of the total number of unemployed, and their proportion fluctuated between 9% and 24% over the period. This is an average of about one million workers, and it constituted between 250,000 workers and 2.5 millions workers over the period.³

7.2.3 Other tests

A third path could be explored to test the importance of job rationing. We saw that the predictions of a model with job rationing regarding the effectiveness of labor market policies are drastically different from those of models without rationing, and are also quite stark. It may be fruitful to tie the policy-related results derived in this dissertation to the empirical literature that attempts to assess the impact of active labor market policies. In fact, this literature is steadily growing, especially in Europe. Empirical comparisons across policies, or within policies across the business cycle, could help find the most adequate model of the labor market.

²The BLS defines a layoff as a suspensions without pay, lasting or expected to last more than seven consecutive calendar days, initiated by the firm without prejudice to the worker.

³As pointed out by Lilien (1980), even though most laid-off are rehired (at least in manufacturing), a large fraction of job losers unemployed are not temporary layoff because the duration of temporary layoff is a lot shorter than the duration for other job losers.

Yet, I am aware of no result that could be compared to the theoretical predictions made here. For instance, the effects of public-job creation during the Great Depression does not seem to be well understood yet. Some scholars find no crowding-out at all (for example, Wallis and Benjamin 1981, Sundstrom 1995), while others find a one-for-one crowding out of the private sector (for example, Fleck 1999). Moreover, studies of the interaction of labor market policies with the business cycle abstract from general-equilibrium effects to focus on treatment effects; that is, they may show that a jobseeker who receives counseling is more likely to find a job, but they cannot tell whether it is a job taken away from somebody else who did not benefit from counseling, or a job newly created by the improvement of the matching process (for example, Kluve et al. 2007, Raaum et al. 2002). Finally, a few meta-studies have investigated the role of economic conditions on policy effectiveness (for example, Kluve 2007). However, these studies have only interacted the state of the labor market with a measure of the aggregate effectiveness of active labor market policies, but not with the effectiveness of individual labor market policies. Therefore, this empirical exercise is so far too simple to test the predictions of my model. Refining empirical policy assessment exercises in light of the findings put forth in this dissertation could help not only test the model with job rationing, but more importantly better understand the impact of active labor market policies of the business cycle.

7.3 Shocks

The model is simplistic in that there are only technology shocks. There is a large body of evidence suggesting that not only technology shocks but also demand shocks drive economic fluctuations at business-cycle frequency (for example, DeLong and Summers 1988, Galí 1999, Galí 2004). Fortunately, the results derived in the dissertation do not require technology shocks. For example, I showed in a previous version of Chapter 5 that the same results would hold in a simple search-and-matching model in which: (i) wages exhibit some nominal rigidity; (ii) firms face a downward-sloping aggregate demand curve in the goods market, and (iii) business cycles are driven by aggregate demand shocks. The combination of a downward-sloping aggregate demand curve and nominal rigidity yields job rationing, and the fluctuations of unemployment and its components in response to demand shocks are similar to those described above. Future work could explore in more detail how demand shocks or financial disturbances affect the behavior of unemployment and its components.

7.4 The Role of Layoffs

In this dissertation, I have always assumed that the rate of job destruction is exogenous and constant. This choice was made mostly for methodological reasons. I wanted to keep the model simple enough to be analytically tractable, and I wanted to follow the standard model

of the literature, which assumes a constant exogenous rate of job destruction (for example, Pissarides 2000, Shimer 2005, Hall 2005a, Hall and Milgrom 2008).

From an empirical point of view however, the literature is divided regarding the cyclicity of the job destruction rate, and the importance of job destructions to explain fluctuations in unemployment. On the one hand, Shimer (2007) argues that since 1948, the job finding probability has accounted for three-quarters of the fluctuations in the unemployment rate in the United States and the employment exit probability for one-quarter. He goes further and finds that fluctuations in the employment exit probability are quantitatively irrelevant during the last two decades: 95% of the fluctuations in the unemployment rate since 1987 were a consequence of movements in the job finding probability. His point of view is supported by Hall (2005a), who sees stability of the Beveridge curve as an argument against the importance of spontaneous burst of separations as a driving force of fluctuations in vacancies and unemployment. Indeed, as noticed by Shimer (2005), increase in job separation rates tend to increase both unemployment and vacancy rates, thus shifting outwards the Beveridge curve.⁴

Nevertheless, recent evidence has questioned this finding to suggest that job separations do actually play an important role to understand unemployment dynamics. Elsby et al. (2009) highlight the particularly important role of job loss inflows to unemployment in accounting for increased unemployment in most recessions. The authors find that much of cyclical unemployment variation can be attributed to cyclicity in the outflow rate, but also find an important role for inflows, especially in the most severe recessions. Fujita and Ramey (2007a) and Fujita and Ramey (2007b) find that separation rates are highly countercyclical. They suggest that fluctuations in the separation rate explain between 40% and 50% of fluctuations in unemployment, implying an important role for the separation rate in explaining the cyclical behavior of unemployment. Finally, by studying the labor markets in France, the U.K., and Spain, Petrongolo and Pissarides (2008) propose that the role of inflows into and outflow from unemployment may play different role across countries. They show that institutions play a major role to understand unemployment fluctuations.

In light of recent evidence, it seems that flows out of employment are countercyclical, in particular because layoffs are quite countercyclical. Hence, understanding these job destructions and their interaction with job rationing should be explored in future research. To do so, we will first need to understand why there are layoffs, and why workers cannot renegotiate wages downward to avoid Pareto-inefficient separation. Answering this question requires a better understanding of the wage-setting mechanism in firms.

⁴How do we reconcile with idea that layoffs are countercyclical with this argument? In fact, quits are procyclical, layoffs countercyclical. So the separation rate may be roughly constant if these two movements balance each other.

7.5 Wage-Setting Mechanisms

Although I propose a simple wage rule that yields job rationing, I do not propose an associated wage-setting mechanism. The rigid wage schedule specified is theoretically valid as it is one of many equilibrium outcomes, and it is empirically valid as my wages are just as flexible as in microdata. But we would like to understand where the wage rigidity comes from. Insights from ethnographic studies of the workplace and empirical evidence suggest that job rationing is a reality of the labor market. Yet it cannot be generated by standard wage-setting mechanisms. An important agenda for future research is to design a tractable wage-setting mechanism explaining the wage rigidity observed in the data, to improve our understanding of job rationing.

Microfounded models of wage rigidity have recently been developed to improve realism of the wage setting. For instance, Kennan (2006) uses asymmetric information in a search model; Rudanko (2009) builds a model in which long-term contracting and insurance motives between risk-neutral firms and risk-averse agents yield wage rigidity; Elsby (2009) builds a dynamic model of downward nominal wage rigidity based on loss aversion. However, these models remain too complex to be analytically tractable in macroeconomic models. Hence, this question should be a priority for future research.

7.6 Optimal Unemployment Insurance

It is often argued that reducing the generosity of unemployment-insurance programs provides an incentive for jobseekers to increase their search intensity, because it makes the state of being unemployed more uncomfortable. Higher search efforts in turn reduce aggregate unemployment. This view is for instance relayed in an article of *The Economist* that reads:⁵

It may seem heartless to counsel against too much support for the unemployed but incentives matter even when unemployment is high. Firms in rich countries make hires equivalent to some 14-15% of all employment in deep recessions, according to the OECD. (Net job creation falls because there are more lay-offs.) *More generous benefits will mean vacancies are filled less quickly, pushing up unemployment.*

This intuition is natural in a search-and-matching framework, which emphasizes the link between search efforts on unemployment. When matching is central, so are search efforts, and policies decreasing search efforts, such as generous unemployment benefits, should be avoided.

On the contrary, this dissertation argued that matching frictions are not relevant to understanding unemployment in recessions. As shown on Figure 7.2, a change in matching

⁵The Economist, November 5th, 2009 “Pay for Delay”. Italics added.

frictions only has a small effect on aggregate unemployment in recessions. Therefore, a reduction in search efforts exerted by unemployed workers—equivalent to increasing matching frictions— may only lead to a negligible increase in unemployment during recessions, and the effect highlighted by the Economist can be neglected.

Since lower search efforts only have a small effect on unemployment, a more generous unemployment-insurance program does not increase unemployment much when the labor market is depressed. Hence, increasing or extending unemployment benefits in recessions does not distort the labor market through the search-activity channel. This result is important at a time when governments decide on the generosity of unemployment-insurance programs, and it should be formalized in future research. Future research would enrich the model to include imperfect risk-sharing across workers and endogenous search effort. It would also endogenize the wage-setting mechanism to understand the possible influence of unemployment benefits on wage level.

Appendix 7.A Calibration of the MP, MPS, and SZ Models

7.A.1 MP model

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

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

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

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

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

7.A.2 MPS model

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

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

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

7.A.3 SZ model

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

$$\bar{w} = \beta [\kappa \cdot \bar{n}^{\alpha-1} + c \cdot (1 - s) \cdot \delta \cdot \bar{\theta}] \quad (7.1)$$

$$(1 - \beta) \cdot \kappa \cdot \bar{n}^{\alpha-1} = [1 - \delta(1 - s)] \frac{c}{q(\bar{\theta})} + c \cdot (1 - s) \cdot \delta \cdot \beta \cdot \bar{\theta} \quad (7.2)$$

$$\bar{l}s = \bar{w} \cdot \bar{n}^{1-\alpha}. \quad (7.3)$$

Combining (7.1), (7.2), and (7.3), and using $c = 0.32 \times \bar{w}$ yields:

$$\kappa = \left[(1 - \delta \cdot (1 - s)) \frac{0.32}{q(\bar{\theta})} + 1 \right] \bar{l}s \quad (7.4)$$

$$\bar{l}s = \bar{w} \cdot \bar{n}^{1-\alpha} \quad (7.5)$$

$$\bar{w} = \beta [\kappa \cdot \bar{n}^{\alpha-1} + c \cdot (1 - s) \cdot \delta \cdot \bar{\theta}]. \quad (7.6)$$

Equation (7.4) identifies $\kappa = 0.67$, given that I target $\bar{l}s = 0.66$ and $\bar{\theta} = 0.45$. Equation (7.5) then determines $\bar{w} = 69$, given that I target $\bar{n} = 0.95$. Finally, (7.6) determines $\beta = 0.86$. I can then calculate $\alpha = \frac{\kappa - \kappa\beta}{1 - \kappa\beta} = 0.21$. To compute the moments from the SZ model, I need to log-linearize it. Only two equations differ between the job-rationing model and the SZ model:

- Wage rule:

$$\check{w}_t = s_1 [\check{a}_t + (\alpha - 1) \cdot \check{n}] + (1 - s_1) \mathbb{E}_t [\check{\theta}_{t+1}],$$

$$\text{with } s_1 = \frac{\beta \cdot \alpha}{1 - \beta(1 - \alpha)} \cdot \frac{\bar{n}^{\alpha-1}}{\bar{w}}.$$

- Firm's Euler equation:

$$\check{a}_t + (\alpha - 1) \cdot \check{n}_t - s_2 \cdot \eta \cdot \check{\theta}_t + [s_2 \cdot (\eta - 1) \cdot \delta \cdot (1 - s) - 1 + s_2] \mathbb{E}_t [\check{\theta}_{t+1}] = 0,$$

$$\text{with } Q = \frac{(1 - \beta) \cdot \alpha}{1 - \beta \cdot (1 - \alpha)} \cdot \bar{n}^{\alpha-1} \text{ and } s_2 = \frac{c}{q(\bar{\theta})} \frac{1}{Q}.$$

Appendix 7.B Tables and Graphs

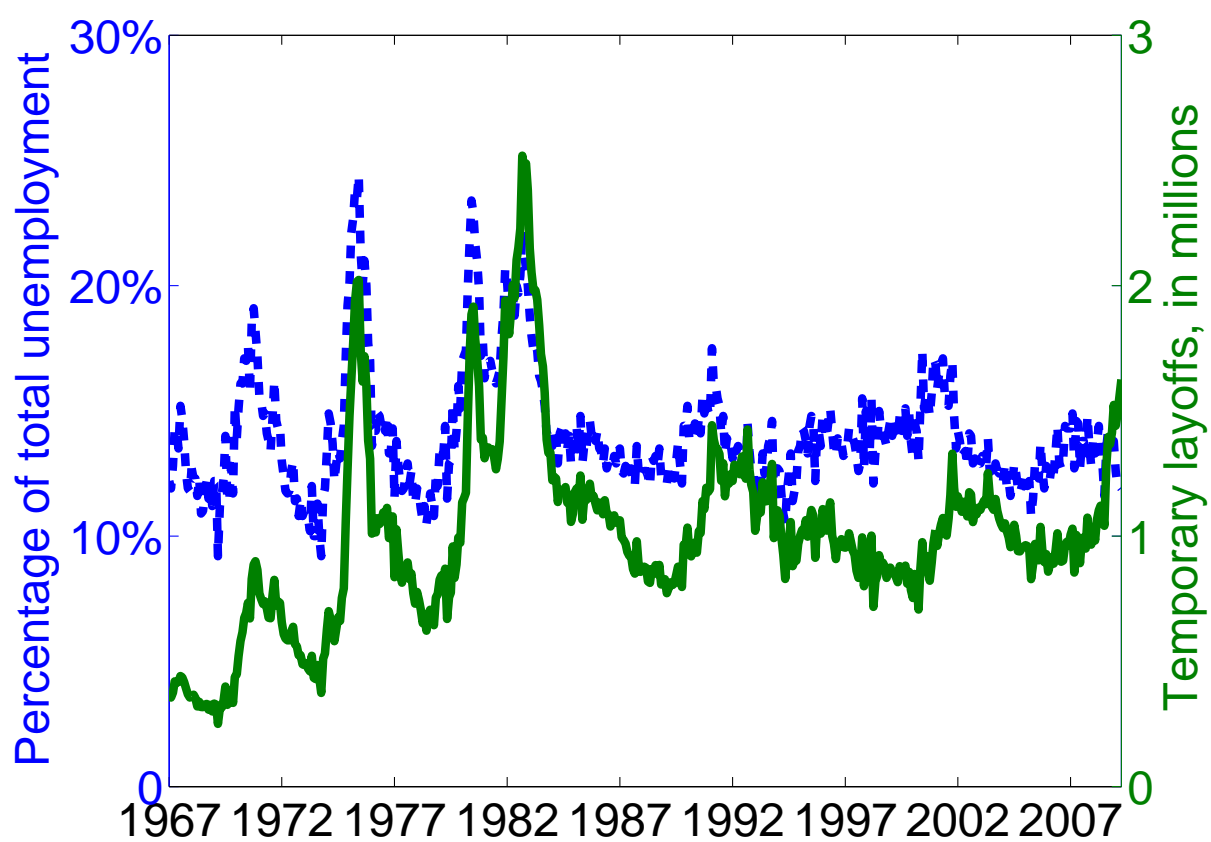


Figure 7.1: The importance of temporary layoffs in the U.S., 1967–2009. Volume of temporary layoffs (plain line) and percentage of unemployed on temporary layoffs (dotted line) are computed by the BLS from the CPS.

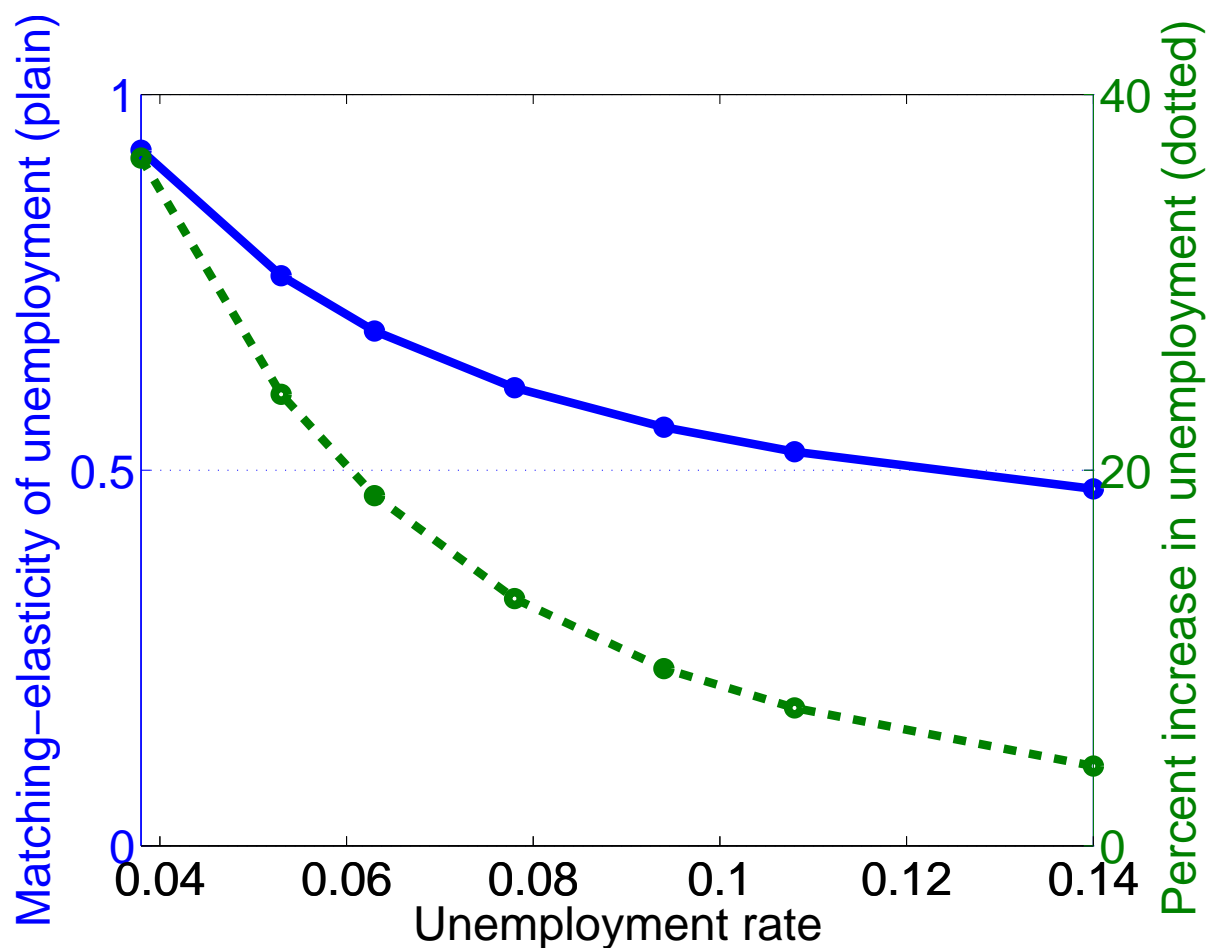


Figure 7.2: Effect on unemployment of reducing the effectiveness of matching ω marginally (plain), and by 50% (dotted).

	Interpretation	Value	Source
s	Separation rate	0.95%	JOLTS, 2000–2009
δ	Discount factor	0.999	Corresponds to 5% annually
ω	Efficiency of matching	0.23	JOLTS, 2000–2009
η	Elasticity of job-filling	0.5	Petrongolo and Pissarides (2001)
$\mathbb{E}[a]$	Mean productivity	1	Normalization
ρ	Autocorrelation of productivity	0.991	MSPC, 1964–2009
σ	Conditional variance of productivity	0.0026	MSPC, 1964–2009
MP model:			
c	Recruiting costs	0.32	$0.32 \times \bar{w}$
β	Worker’s bargaining power	0.86	Matches unemployment = 5.8%
MPS model:			
c	Recruiting costs	0.32	$0.32 \times \bar{w}$
w_0	Steady-state real wage	0.991	Matches unemployment = 5.8%
SZ model:			
c	Recruiting costs	0.22	$0.32 \times \bar{w}$
α	Returns to labor	0.21	Matches labor share= 0.66
β	Worker’s bargaining power	0.86	Matches unemployment = 5.8%

Table 7.1: Parameter values used in simulations of benchmark models. Section 5.4 and Appendix 7.A provide details on the calibration strategy. All parameters are calibrated at weekly frequency.

Model	U	θ
U.S. data	0.17	0.34
Baseline	0.133 (0.020)	0.287 (0.041)
Mortensen-Pissarides	0.008 (0.001)	0.018 (0.002)
Mortensen-Pissarides-Sticky, $\gamma = 0$	1.026 (0.157)	4.708 (1.140)
Mortensen-Pissarides-Sticky, $\gamma = 0.7$	0.308 (0.059)	0.691 (0.141)
Stole-Zwiebel	0.008 (0.001)	0.018 (0.003)

Table 7.2: Standard deviations from simulating the baseline, MP, MPS, and SZ models with stochastic productivity. All variables are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 5.5.3 provides details on the simulation. Tables 5.C, 7.B, 7.B, 7.B, and 7.B display all the complete set of simulated moments of the job-rationing model, the MP model, MPS model with $\gamma = 0$, MPS model with $\gamma = 0.7$, and SZ model. Table 5.C reports all the estimated moments in U.S. data, as well as data sources.

	U	V	θ	W	Y	a
Standard Deviation	0.008 (0.001)	0.010 (0.001)	0.018 (0.002)	0.018 (0.002)	0.019 (0.003)	0.018 (0.002)
Autocorrelation	0.929 (0.020)	0.837 (0.043)	0.902 (0.027)	0.866 (0.036)	0.869 (0.035)	0.866 (0.036)
	1	-0.927 (0.019)	-0.978 (0.006)	-0.983 (0.004)	-0.984 (0.004)	-0.983 (0.004)
	—	1	0.985 (0.004)	0.935 (0.017)	0.935 (0.018)	0.935 (0.017)
	—	—	1	0.975 (0.007)	0.975 (0.007)	0.975 (0.007)
Correlation	—	—	—	1	1.000 (0.000)	1.000 (0.000)
	—	—	—	—	1	1.000 (0.000)
	—	—	—	—	—	1

Table 7.3: Simulated moments in the MP model. Results from simulating the MP model with stochastic productivity. All variables are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 5.5.3 provides details on the simulation.

	U	V	θ	W	Y	a
Standard Deviation	1.026 (0.157)	3.923 (1.029)	4.708 (1.140)	0.000 (0.000)	0.306 (0.149)	0.018 (0.002)
Autocorrelation	0.938 (0.022)	0.716 (0.075)	0.791 (0.055)	0.995 (0.000)	0.923 (0.041)	0.866 (0.036)
	1	-0.703 (0.052)	-0.806 (0.039)	-0.000 (0.000)	-0.867 (0.034)	-0.925 (0.013)
	—	1	0.987 (0.005)	0.000 (0.000)	0.644 (0.064)	0.726 (0.047)
	—	—	1	-0.000 (0.000)	0.728 (0.051)	0.809 (0.031)
Correlation	—	—	—	1	-0.000 (0.000)	-0.000 (0.000)
	—	—	—	—	1	0.727 (0.040)
	—	—	—	—	—	1

Table 7.4: Simulated moments in the MPS model with $\gamma = 0$. Results are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 5.5.3 provides details on the simulation.

	U	V	θ	W	Y	a
Standard Deviation	0.308 (0.059)	0.402 (0.086)	0.691 (0.141)	0.013 (0.002)	0.042 (0.010)	0.018 (0.002)
Autocorrelation	0.931 (0.022)	0.814 (0.045)	0.894 (0.029)	0.866 (0.036)	0.906 (0.031)	0.866 (0.036)
	1	-0.895 (0.024)	-0.966 (0.009)	-0.966 (0.006)	-0.992 (0.003)	-0.966 (0.006)
	—	1	0.980 (0.004)	0.898 (0.016)	0.881 (0.027)	0.898 (0.016)
	—	—	1	0.953 (0.008)	0.954 (0.011)	0.953 (0.008)
Correlation	—	—	—	1	0.962 (0.017)	1.000 (0.000)
	—	—	—	—	1	0.962 (0.017)
	—	—	—	—	—	1

Table 7.5: Simulated moments in the MPS model with $\gamma = 0.7$. Results from simulating the MPS model with stochastic productivity, when $\gamma = 0.7$. All variables are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 5.5.3 provides details on the simulation.

	U	V	θ	W	Y	a
Standard Deviation	0.008 (0.001)	0.010 (0.001)	0.018 (0.003)	0.018 (0.003)	0.018 (0.003)	0.018 (0.003)
Autocorrelation	0.926 (0.024)	0.836 (0.048)	0.901 (0.031)	0.863 (0.043)	0.865 (0.042)	0.865 (0.043)
Correlation	1	-0.928 (0.021)	-0.978 (0.007)	-0.983 (0.005)	-0.984 (0.005)	-0.984 (0.005)
	—	1	0.985 (0.004)	0.937 (0.018)	0.936 (0.018)	0.936 (0.018)
	—	—	1	0.975 (0.008)	0.975 (0.008)	0.975 (0.008)
	—	—	—	1	1.000 (0.000)	1.000 (0.000)
	—	—	—	—	1	1.000 (0.000)
	—	—	—	—	—	1
	—	—	—	—	—	1
	—	—	—	—	—	1

Table 7.6: Simulated moments in the SZ model. Results from simulating the log-linearized SZ model with stochastic productivity. All variables are reported as logarithmic deviations from steady state. Simulated standard errors (standard deviations across 200 model simulations) are reported in parentheses. Section 5.5.3 provides details on the simulation.

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