

JOB SEARCH AND WAGE BARGAINING

A Dissertation
submitted to the Faculty of the
Graduate School of Arts and Sciences
of Georgetown University
in partial fulfillment of the requirements for the
degree of
Doctor of Philosophy
in Economics

By

Jordan Marcusse, M.Phil.

Washington, DC
June 9, 2016

Copyright © 2016 by Jordan Marcusse
All Rights Reserved

JOB SEARCH AND WAGE BARGAINING

Jordan Marcusse, M.Phil.

Dissertation Advisor: A. Anderson, Ph.D.

ABSTRACT

This dissertation is a collection of three studies into the nature of job search, job vacancy creation, and the determination of wages.

In the first chapter I develop a theory of wage determination in a bargaining environment with features found in the labor market, where a buyer and a seller produce repeatedly in a dynamic environment with the possibility of renegotiation. I model a bargaining game of alternating offers and show that as the time between counteroffers goes to zero, there is a single equilibrium wage in each state of the world. The equilibrium wage is Nash's bargaining solution where the surplus to be shared is a linear combination of the surplus from exchange over an instant and the surplus from exchange over the duration of the match.

In the second chapter I investigate the driving forces of business cycle fluctuations of unemployment and vacancies in an environment with search frictions and endogenous job vacancy creation. In a calibrated model of search and matching, productivity shocks alone generate excessive volatility of vacancies relative to unemployment. Including shocks to the separation rate generates relative volatilities of vacancies and unemployment that more closely approximate what is observed in the data. I also show that the countercyclicality of measured productivity in recent decades does not align with the cyclical behavior of the labor market.

In the third chapter I propose a framing of wage bargaining between firms and workers in which the surplus to be split is the flow benefit from production rather than the surplus over the duration of the match. Embedding this wage bargain in

a model of search and matching in the labor market, I am able to reproduce the business cycle behavior of the Beveridge curve observed in US data more closely than under alternative models of wage bargaining.

INDEX WORDS: Unemployment, Vacancies, Wages, Business Cycles, Bargaining, Search Frictions

ACKNOWLEDGMENTS

There are many people who have helped me along the way to completing my studies and dissertation, too many to thank by name. To start, I am grateful to my classmates, for fun times together and for their helpful thoughts on research, presentations, and the job market. I also want to thank our graduate coordinators Barbara Kalabinski and Julius Shapiro for their help and for lending a friendly ear throughout my time at Georgetown.

I want to thank my advisor Axel Anderson for his guidance and support, along with my committee members Susan Vroman and Jim Albrecht for their help and wisdom. I want to thank Luca Flabbi, who began as my advisor in 2012, and got me started in labor market research. Lastly, while he hasn't advised me in any official capacity, I am grateful to Arik Levinson for helping me to grow as a speaker, presenter, and teacher.

On a personal note, I want to thank my family. My parents Jack and Nancy have always been there for me. I am grateful to my wife Katie for her patience and support during this long, long process. Lastly, I want to thank my daughter Trixie for making sure that I start and end each day with a smile.

TABLE OF CONTENTS

INTRODUCTION	1
CHAPTER	
1 Bargaining in an Ongoing Exchange with Renegotiation	5
1.1 Introduction and related literature	5
1.2 The model	8
1.3 Nash bargaining	20
1.4 Conclusion	25
2 Job Separations and the Cyclicalities of Unemployment and Vacancies	27
2.1 Introduction	27
2.2 Characterizing equilibrium	29
2.3 Calibration and shocks	32
2.4 Simulation	47
2.5 Discussion	55
2.6 Conclusion	56
3 Wage Bargaining and the Beveridge Curve	57
3.1 Introduction and related literature	57
3.2 Observations of the US labor market	61
3.3 Matching	79
3.4 Bargaining	82
3.5 Calibration and estimation	86
3.6 Results	93
3.7 Conclusion	103
APPENDICES	
A Appendix to Chapters 1, 2, and 3: Data sources	105
B Appendix to Chapter 1	106
B.1 Proof of subgame perfect equilibrium	106
C Appendix to Chapter 3	110
C.1 Notes on JOLTS vacancy data	110
C.2 Conference Board data	111

LIST OF FIGURES

I.1	Unemployment, employment, and job openings over time	2
1.1	Production subgame of the bargaining game	13
1.2	Non-production subgames of the bargaining game	14
1.3	Values of worker bargaining power derived from match breakdown probabilities	24
2.1	Determination of unemployment and vacancies by the Inflow-Outflow condition and the Zero Profit condition	31
2.2	Wald statistic for structural break from regression of cyclical indicators on productivity	35
2.3	Wald statistic for structural break from regression of cyclical indicators on separations	36
2.4	Kernel estimation of the probability density of realizations of productivity and the separation rate, from detrended data, 1951-1983	40
2.5	Graphical representation of the density of productivity and separation rate realizations estimated in Table 2.5	40
2.6	Kernel estimation of the probability density of realizations of productivity and the separation rate, from detrended data, 1984-2013	41
2.7	Graphical representation of the density of productivity and separation rate realizations estimated in Table 2.6	41
2.8	Rolling estimates of the matching elasticity parameter	43

2.9	Fluctuations in vacancies and unemployment from data and the Inflow- Outflow curve	45
2.10	Fluctuations in vacancies and unemployment from data and from var- ious shocks	49
2.11	Fluctuations in vacancies and unemployment from data and from sim- ulations, 1951-1983	52
2.12	Fluctuations in vacancies and unemployment from data and from sim- ulations, 1984-2013	53
3.1	Labor market tightness and low-frequency trend	61
3.2	Log unemployment and low-frequency trend	64
3.3	Log vacancies and low-frequency trend	66
3.4	Beveridge curve	67
3.5	Business cycle behavior of Beveridge curve	68
3.6	Job-finding rate and low-frequency trend	70
3.7	Job-finding rate and labor market tightness	71
3.8	Separation rate and low-frequency trend	72
3.9	Separation rate and labor market tightness	73
3.10	Aggregate productivity and low-frequency trend	74
3.11	Productivity and labor market tightness	75
3.12	Contemporaneous correlation between productivity and tightness over 20-year rolling windows	76
3.13	Timeline for the models in this paper	79
3.14	The Nash and KS bargaining outcomes	84
3.15	Beveridge curves from simulation with productivity and separation rate shocks	94
3.16	Beveridge curves from simulation with productivity shocks only	97

C.1 Comparison of vacancy data series 112

LIST OF TABLES

1.1	Parameters for the bargaining game	12
2.1	Structural break regression to test for changing cyclical behavior of productivity	35
2.2	Structural break regression to test for changing cyclical behavior of separations	36
2.3	AR(1) regression of log HP-filtered productivity, 1951-1983	37
2.4	AR(1) regression of log HP-filtered productivity, 1984-2013	37
2.5	VAR(1) estimation of productivity and separations processes, 1951- 1983	39
2.6	VAR(1) estimation of productivity and separations processes, 1984- 2013	39
2.7	Estimating the matching elasticity parameter	43
2.8	Parameter and steady state values over subsamples of the data . . .	44
2.9	Estimating elasticity of vacancies with respect to unemployment . .	45
2.10	Comparative statics from shocks to matching parameters and the sep- aration rate	49
2.11	Comparison of simulations to data, 1951-1983	54
2.12	Comparison of simulations to data, 1984-2013	54
3.1	Estimation of matching parameters	88
3.2	Estimation of VAR(1) matrix A for productivity and the separation rate	90
3.3	Estimation of VAR(1) variance matrix Σ	90

3.4	Calibrated parameters	92
3.5	Calibrated values of leisure parameter z	92
3.6	Simulated results, productivity and separation rate shocks	95
3.7	Simulated results, productivity shocks only (risk neutral workers)	98
3.8	Effect of productivity shocks on the wage and value of a filled job opening	99
3.9	Effect of separation rate shocks on the wage and value of a filled job opening	99
3.10	Matching wage fluctuations in Solon, Barsky, and Parker	102
C.1	Estimation of vacancy series overlap	111

INTRODUCTION

This dissertation is a collection of work studying wage bargaining, job search, and job creation. For many people, these matters are some of the most trenchant in economics. In the Survey of Consumers by the University of Michigan, news about employment and unemployment have constituted about 50% of all responses when consumers are asked about business conditions.¹ It is my goal to contribute to our understanding of these matters. The three chapters of this thesis approach the economic theory related to unemployment along with job creation and bargaining over wages.

The market for labor is characterized by the simultaneous existence of large stocks of unsold supply (unemployment) and unmet demand (job vacancies). Unemployment and vacancies both exhibit large fluctuations over the business cycle and their fluctuations have a strong negative correlation. This is reflected in Figure I.1, which is a graph of unemployment, employment, and vacancies, relative to the total labor force. While unsold supply and unmet demand fluctuate, the price of labor (the wage) varies only moderately over the business cycle.

Each chapter in this dissertation takes place in an environment with search. Consider a market with two types of agents who search in order to meet and exchange goods. For simplicity of terminology, I will refer to one type of agent as the buyer of a good, and the other type of agent as the seller. When a buyer and seller meet, the buyer's (seller's) surplus from transacting with any specific seller (buyer) is the net benefit from that transaction minus the net benefit from the best alternative.

¹Data from 1978 to 2016, average of monthly percentages.

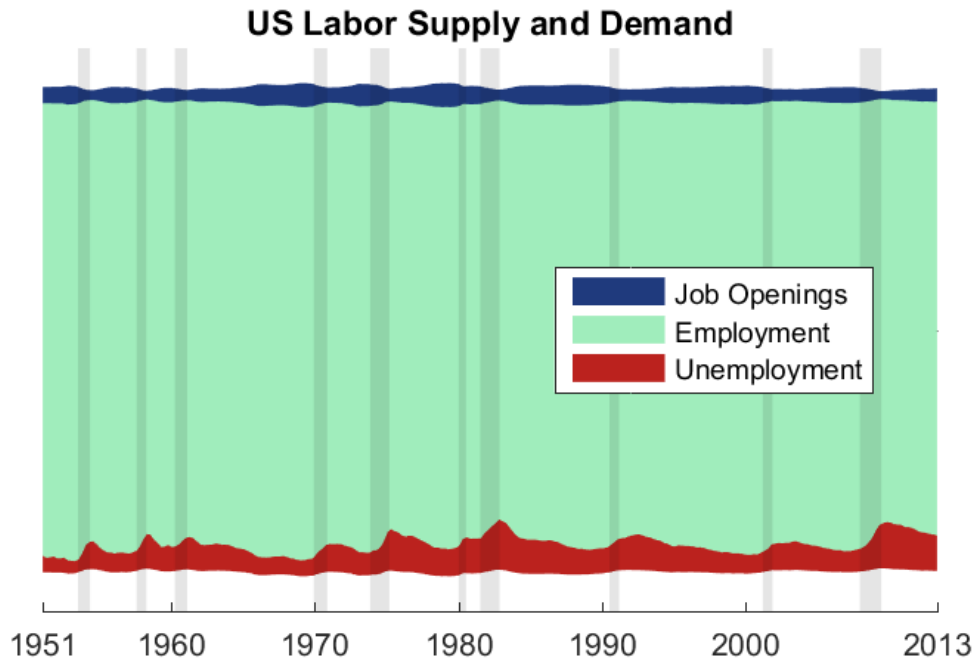


Figure I.1: Unemployment, employment, and job openings over time. Data are quarterly, 1951Q1-2013Q2. Bars represent recessions. Source: Appendix A.

The best alternative may be a transaction with a different seller (buyer), and the net benefit of carrying out this transaction is reduced by any cost in terms of time, material, or uncertainty incurred while searching for that seller (buyer). I will refer to this best alternative as the outside option.

In a Walrasian market a buyer (seller) of a good can immediately, costlessly, and with certainty turn to another seller (buyer). In this case, neither the buyer nor the seller has an incentive to deviate from the common market price. As matched buyers (sellers) are just as well off transacting at the market price as they are finding other sellers (buyers) and transacting at the same price, the surplus from any specific trade at the market price is of value zero. In a Walrasian market, there is no benefit to

transacting with a specific partner relative to any other. The market price adjusts instantly until there is no unsold supply or unmet demand.

Instead of a Walrasian market, consider a market where buyers and sellers search in order to meet and exchange goods, but this search takes time. When a buyer and a seller meet, trading can result in a positive surplus. A buyer's (seller's) best alternative to exchanging with their current seller (buyer) under the proposed terms may be to search for a different partner or to continue bargaining. There is a time cost to searching. There are two opportunity costs to continued bargaining: a cost from delay and a risk that the seller (buyer) leaves before bargaining concludes. In this way, search frictions allow for a positive surplus from trade between two specific partners. Bargaining then provides a means of determining a division of this surplus.

In the first chapter of this dissertation I develop a model of bargaining in an ongoing relationship in a dynamic environment without commitment. It is a theoretical approach to modeling wage bargaining. In the literature, wage bargaining is often modeled as a one-time bargain, where a firm and worker meet, agree to a wage or a schedule of state-contingent wages, then produce until the match ends. The contribution in this paper is to approach a wage bargain as an agreement that can be revisited at any time. The resulting equilibrium wage outcome exhibits similar properties to the outcome of a one-time bargain in terms of the relevant outside options that determine the outcome, but with a wage that changes over time.

In the second chapter I demonstrate two issues with using productivity as the sole driving force for modeling labor market volatility. Using a simple model with minimal assumptions, I show that fluctuations to productivity alone drive excessive fluctuations in job vacancies relative to fluctuations in unemployment. Adding separation rate fluctuations to the model brings the simulated results more in line with the data. I also show that the countercyclicality of productivity since 1984 is an issue

for the common practice of applying productivity as the primary driver of business cycle fluctuations in the labor market. I suggest that adjustments for cyclical variations to productive inputs may help generate a measure of productivity that retains the cyclical behavior exhibited prior to 1984.

In the third chapter I apply the implications of the first two chapters to resolve a puzzling observation from business cycle data: the large volatility exhibited by unemployment and vacancies relative to the postulated drivers of labor market fluctuations. I test the ability of a basic labor search model with various wage bargaining formulations to match the data. The bargaining model in which the relevant surplus is the flow returns to production best matches the data, particularly when workers are risk neutral. I also demonstrate that fluctuations in the separation rate are an important driver for matching the relative volatility of unemployment and vacancies.

CHAPTER 1

BARGAINING IN AN ONGOING EXCHANGE WITH RENEGOTIATION

1.1 INTRODUCTION AND RELATED LITERATURE

This paper studies bargaining between two agents involved in an ongoing productive relationship in a dynamic environment without commitment to a schedule of payoffs. The analysis is intended to mirror bargaining between workers and firms over the terms of employment. The wage determines the allocation of the surplus from production. This surplus changes over time with productivity, resulting in an exchange that occurs repeatedly in a stochastic dynamic environment in which it is not possible to commit to a contingent contract of future wages that spans all eventualities.

Bargaining is a method of determining the division of a surplus between two¹ parties. The seminal paper in bargaining theory is Nash (1950), who shows that there is a unique solution to the division of a convex surplus space that satisfies the four axiomatic properties of Pareto efficiency, independence from irrelevant alternatives, symmetry, and invariance to affine transformations of the utility representations. Rubinstein (1982) relates the Nash bargaining solution to an alternating offer bargain in which declining and proposing a counteroffer reduces the value of the surplus to be split. As the time between counteroffers goes to zero, the equilibrium wage approaches the Nash bargaining outcome.

¹or more

This shrinking of the surplus may be due to the cost of delay or a risk of the surplus being lost. Binmore et al. (1986) make explicit this contrast between time preference and the loss of the surplus which occurs when the match breaks down. An implication of this distinction is that the relevant outside option, the alternative to sharing the surplus, depends on which form the opportunity cost of proposing a counteroffer takes.

The bargaining environment in this paper is framed as bargaining under search and matching. The solution methodology is related to that in Trejos and Wright (1995) and Shi (1995). In their models, agents search until a compatible buyer and seller meet, bargain over the terms of their exchange, then begin searching again. The bargaining incorporates both a cost from delay and a risk of match breakdown during bargaining.

Most of the research in this field studies a one-time bargain, where there is a single moment at which the division of the surplus is determined. This is a plausible way to describe the market for many goods, particularly large, indivisible goods such as housing. However, in an ongoing relationship the parties may seek to renegotiate the terms of exchange. Workers sell their labor to firms repeatedly, sometimes for several decades, with the match surplus and the wage changing over time. Because labor laws limit the compulsion of labor, a worker and firm can not commit to a schedule of terms of exchange.

There have been previous papers that incorporate some of the features of this analysis. Rudanko (2009) models a wage bargain between risk averse workers and risk neutral firms with limited commitment. In her model, it is efficient to commit to a constant wage, but renegotiations will occur when the surplus from the match becomes negative for either the firm or the worker. Her bargaining method does not incorporate the time cost of bargaining.

In contrast, Holden (1994) describes a scenario of wage-setting with renegotiation in which the relevant outside option is delay, not leaving the match. A wage agreement holds until conditions change sufficiently such that either firms or workers have an incentive to reopen bargaining, due to inflation or changes in demand. However, Holden does not include the risk of match breakdown during bargaining.

One other similar framing of the wage bargain is the work of Hall and Milgrom (2008). In their model, a firm and a worker make an alternating offer bargain with a delay of one business day between the arrival of counteroffers. Continuing to bargain results in both a cost from delay and an increased risk of the match breaking down. As a result, Hall and Milgrom's model incorporates aspects of both outside options, delay and leaving the match. In contrast this paper, by studying the limiting case wherein the time between counteroffers approaches zero, derives an analytical solution to the bargaining problem. This derivation allows for analysis of the relative importance of the two outside options in determining the wage and the result is compatible with renegotiation over time.

The outcome of bargaining derived in this paper is similar to that derived in Brüggemann and Moscarini (2010) under complete information. Their bargaining outcome is the result of a one-time bargain in a static environment. Strikingly, their bargaining outcome has the same structural form as the outcome in this paper, in spite of the differences in the bargaining environment. Bargaining in a dynamic, stochastic environment without commitment leads to a similar specification of the outcome as the environment without dynamics. Of course, the wage outcome is not static in this paper, which allows for a rich analysis of wage dynamics. I conclude with a brief analysis of the dynamics of bargaining power implied by the cyclical behavior of matching.

1.2 THE MODEL

This analysis uses a discrete time model. I will consider some fixed unit of time to have length one. Each period in the model will be a fraction Δ of that fixed unit of time. When a firm and worker match, they bargain over a wage to split the resulting surplus. Periods are the intervals of time over which workers (and firms) can delay and propose a counteroffer during bargaining. In moving from one period to the next, firms and workers discount at rate ρ . The discount rate is given by $\rho = e^{-r\Delta}$, which approximates discounting at rate r per fixed unit of time.

Two parameter values vary exogenously in the game: productivity p and the separation hazard s , together denoted as state x . Productivity is the output from the match during one fixed unit of time, and the separation hazard is the proportion of matches that breaks up during one fixed unit of time. Each period, output is Δp and at the end of the period, the match breaks down with probability $\psi \equiv 1 - e^{-s\Delta}$.

Shocks to the state arrive according to an exponential distribution with arrival rate $\lambda \equiv 1 - e^{-\ell\Delta}$. When a shock to the state occurs, a new state is drawn according to a Markov chain process, which is independent of the value of Δ . Define π_x as the probability that, upon realization of a shock while in state x , the new state is the same as the old state. The expected duration between shocks is $1/\ell$. The expected duration in a single state is $((1 - \pi_x)\ell)^{-1}$.

While matched, workers and firms receive a stage payoff each period. When the match breaks down, they receive a one-time state payoff, the payoff of entering an unmatched state, then the game ends. The total payoff is the discounted sum of the stage payoffs plus the discounted one-time state payoff.

When production takes place, workers derive utility from wage income according to monotone increasing period utility function $\Delta u(w)$, where w is the wage rate. For

each period in which a worker is not working, they receive period utility $\Delta u(z)$, where z denotes the combined value of leisure and non-work income. If the match breaks down, workers enter a state with value $U(x)$. Firms are risk neutral, and derive profit $\Delta(p - w)$ during each period where production takes place. When firms are matched but production does not take place, firms pay cost $\Delta\gamma$. If the match breaks down, firms enter a state with value $V(x)$.²

Throughout, I make Assumption 1.1, which ensures that the non-trivial case, where bargaining is relevant, holds. There is a surplus to producing relative to bargaining, and there is a surplus to being matched relative to leaving the match.

Assumption 1.1 *Existence of surplus*

1. In all states, there is a surplus to production. For workers, I assume $p > z, \forall p$.

For firms, I assume $p > 0 \geq -\gamma, \forall p$.

2. In all states, there is a surplus to remaining matched: $\exists \tilde{w}$ such that

$$\Delta u(\tilde{w}) + \rho U(x') > U(x) \text{ and } \Delta(p - \tilde{w}) + \rho V(x') > V(x), \forall x, x', \Delta$$

1.2.1 A GAME OF WAGE BARGAINING WITHOUT CREDIBLE COMMITMENT

With the payoffs and match dynamics defined, I turn to a description of the bargaining game. This section begins by laying out a game of alternating offers bargaining over ongoing production with the possibility of renegotiation. I define a subgame perfect equilibrium. I derive the equilibrium as the time between counteroffers goes to zero and compare it to Nash's axiomatic bargaining solution. Throughout, I make the following assumption about information and wage determination.

²It is common to assume free entry of vacancy postings, so that $V(x) = 0, \forall x$ in equilibrium, but such an assumption is not necessary for this analysis.

Assumption 1.2 *Information and bargaining*

1. *There is perfect information.*
2. *Firms and workers have rational expectations about the state and bargaining outcomes.*
3. *Neither firms nor workers can precommit to a schedule of wages for subsequent periods, state-contingent or not.*

I assume that there is no credible precommitment to wage schedules, so that the resulting (state-contingent) wage is the solution to a Bellman equation. This stands in contrast to most prior models of wage bargaining, where the outcome of the bargain is a split of the surplus, with either a fixed wage or with the wage dynamics left indeterminate.

I consider an intuitive framework for bargaining: firms and workers have alternating opportunities to propose a wage and to respond. The bargaining outcome is subject to renegotiation in subsequent periods.

When a firm and a worker match, they bargain over the wage by means of a series of offers and counteroffers, one each period. Production and wage payment do not begin until bargaining is concluded. Once an agreement is reached, it holds until either the firm or the worker decide to renegotiate the wage.

In addition to the time cost, rejecting a wage offer increases the probability of the match breaking down. If the firm proposes a wage and the worker rejects, the match breaks down with probability ϕ_W . Similarly, when a firm rejects a wage proposed by the worker, the match breaks down with probability ϕ_F . Together with the per-period separation rate ψ , there is probability $(1 - \phi_W)(1 - \psi)$ that the match remains the period after a worker rejects a wage offer. Similarly, there is probability $(1 - \phi_F)(1 - \psi)$

that the match remains the period after a worker rejects a wage offer. To simplify notation, I introduce terms $\delta_W = \psi + \phi_W(1 - \psi)$, and $\delta_F = \psi + \phi_F(1 - \psi)$, which are the probabilities of match breakdown following a rejected offer.

The match breakdown risk incurred through rejection of a wage offer varies with the duration of a period. Accordingly, $\phi_W = 1 - e^{-B_W\Delta}$ and $\phi_F = 1 - e^{-B_F\Delta}$. Parameters B_W and B_F fix the hazard rate of match breakdown in terms of fixed units of time.

There are several relevant parameters that are functions of their fixed-time unit analogues. These parameters are summarized in Table 1.1.

The bargaining game has three subgames, depicted in Figures 1.1 and 1.2: bargaining when production took place previously at wage w , labeled **Prod**(w, x); bargaining where the firm proposes a wage, labeled **Barg** $_F$ (x); and bargaining where the worker proposes a wage, labeled **Barg** $_W$ (x). Every subgame starts with the values of productivity p and the separation rate s as state variables. The first period, when the firm and worker have no prior wage set, either the worker or the firm proposes a wage with probability $1/2$.

If the worker proposes the wage, they play subgame **Barg** $_W$ (x); if the firm proposes the wage, they play subgame **Barg** $_F$ (x). Let $i \in \{W, F\}$ denote the agent that proposes the wage and $-i$ denote the other agent. If agent i accepts proposed wage w' , production takes place, workers receive benefit $\Delta u(w')$ and firms receive profit $\Delta(p - w')$. After production, the match breaks down with probability ψ , in which case there is a new realization of x' and workers and firms receive their non-match state values $U(x')$ and $V(x')$, discounted by ρ . If the match does not break down, there is a new realization of x' and the next period they play subgame **Prod**(w', x'), which is discounted by ρ . If the proposed wage is rejected, workers receive period payoff $\Delta u(z)$ and firms pay cost $\Delta\gamma$. The match breaks down with probability δ_{-i} , in which

Table 1.1: Parameters for the bargaining game

Parameter	Fixed duration analogue	Formula	Interpretation
ρ	r	$\rho = e^{-r\Delta}$	Discount rate
ψ	s	$\psi = 1 - e^{-s\Delta}$	Probability of match breakdown during production
ϕ_W	B_W	$\phi_W = 1 - e^{-B_W\Delta}$	Probability of match breakdown due to worker rejecting wage offer
ϕ_F	B_F	$\phi_F = 1 - e^{-B_F\Delta}$	Probability of match breakdown due to worker rejecting wage offer
δ_W	$s + B_W - sB_W$	$\delta_W = \psi + \phi_W - \psi\phi_W$	Probability of match breakdown during holdout by workers
δ_F	$s + B_F - sB_F$	$\delta_F = \psi + \phi_F - \psi\phi_F$	Probability of match breakdown during holdout by firms
λ	ℓ	$1 - e^{-\ell\Delta}$	Probability of shock to state
π_x			Probability of shock not changing state

case there is a new realization of x' , and workers and firms receive their non-match state values $U(x')$ and $V(x')$, discounted by ρ . If the match does not break down, there is a new realization of x' and the next period they play subgame **Barg** $_{-i}(x')$, which is discounted by ρ .

When production has taken place in the previous period, workers and firms each have the opportunity to request a renegotiation. If both workers and firms choose not

to renegotiate, production takes place, and workers receive the same wage as in the previous period. If agent $i \in \{W, F\}$ requests the renegotiation and the other agent $-i \neq i$ does not, agent $-i$ proposes a wage w' . If both the worker and the firm request a renegotiation, there is a random draw as to which agent proposes the wage, with probability $1/2$ for either agent.

Bargaining in subgames $\mathbf{Barg}_F(x)$ and $\mathbf{Barg}_W(x)$ is the same as the bargaining in the production subgame, without the option to continue production at the previous period's wage. Consequently, a set of strategies consists of proposed wages, acceptance/rejection of proposed wages, and renegotiation, for both workers and firms.

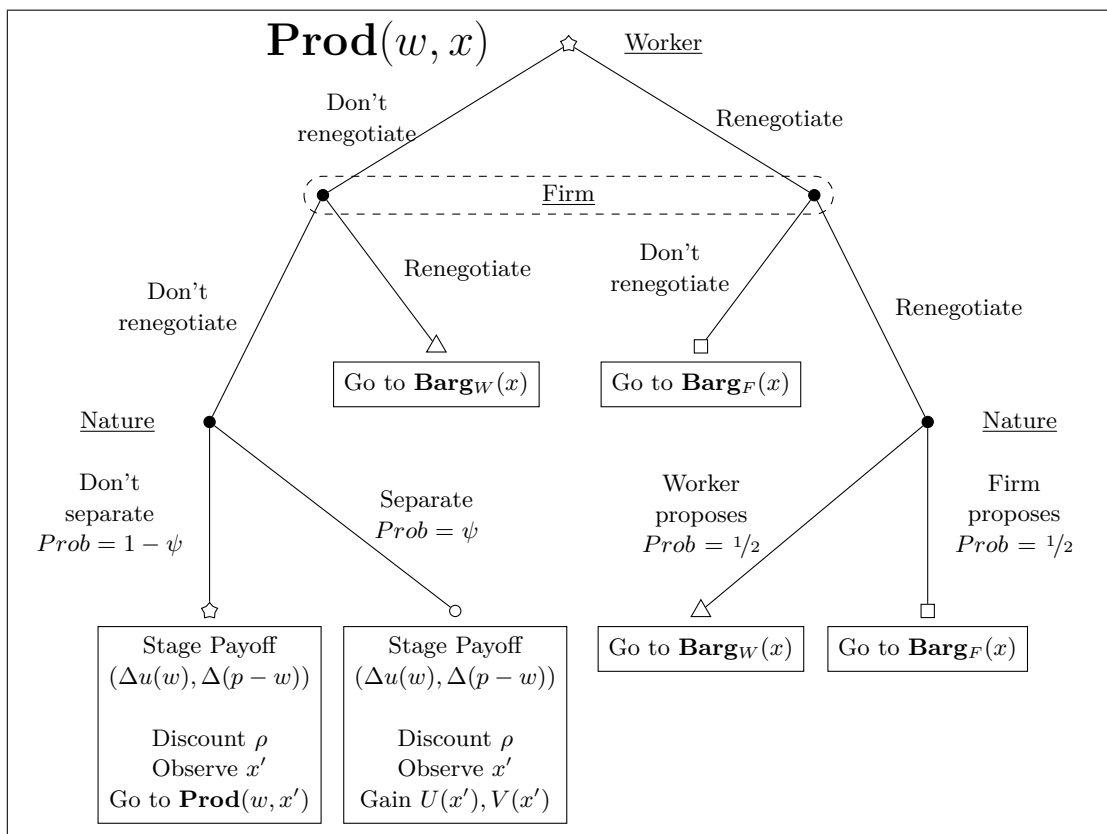
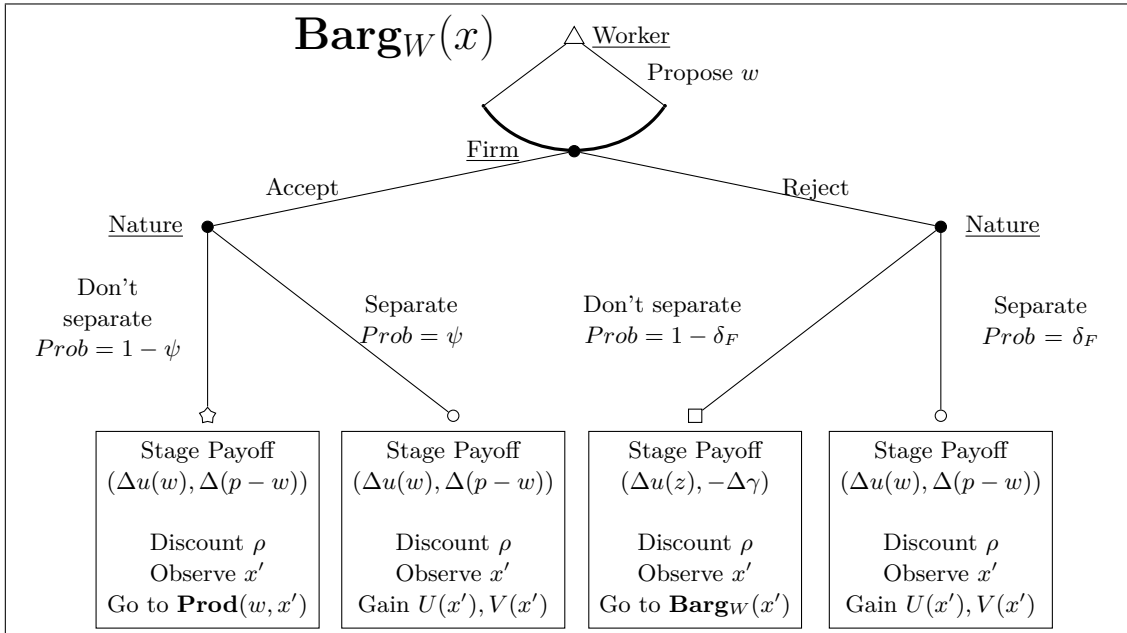
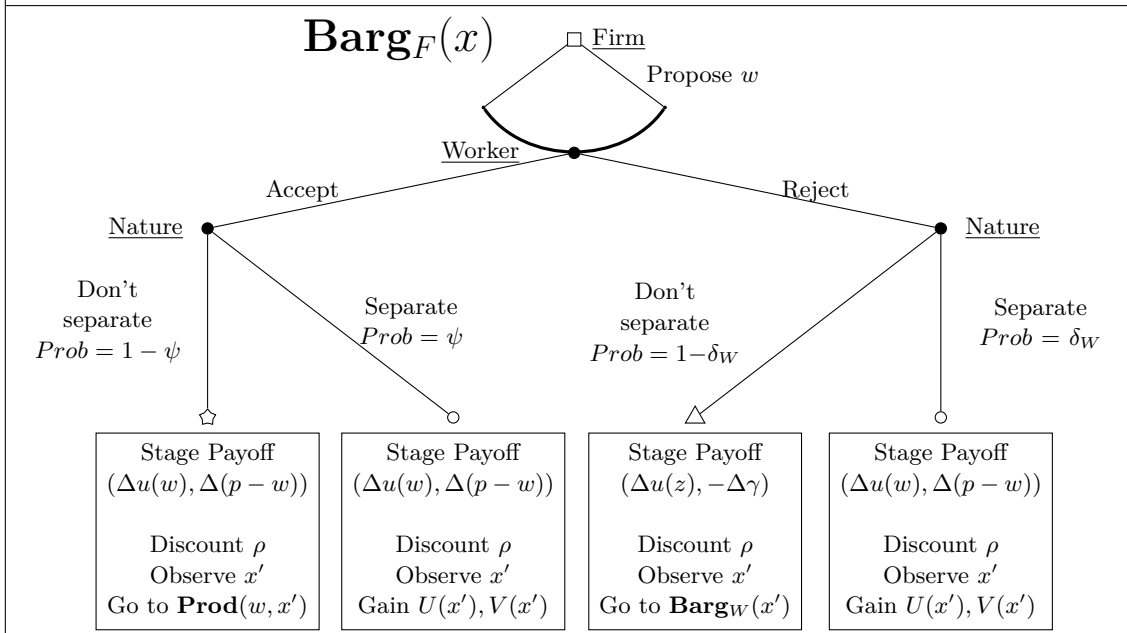


Figure 1.1: Production subgame of the bargaining game. Subgame in which the state is x and production took place in the previous period with wage w .



(a) Bargaining in which the state is x and the worker proposes a wage.



(b) Bargaining in which the state is x and the firm proposes a wage.

Figure 1.2: Non-production subgames of the bargaining game.

1.2.2 A CHARACTERIZATION OF EQUILIBRIUM

In order to propose and characterize an equilibrium set of strategies, I first introduce a set of recursive characterizations of the value of producing under a given wage, as well as a set of conditions laying out state contingent wage strategies. First, let us label the wage strategies. When bargaining in state x , firms propose wage $\underline{w}(x)$. Workers propose $\bar{w}(x)$.

Assumption 1.3 *States and renegotiation*

1. $\forall x, \forall x' \neq x$ either $\bar{w}(x) \leq \underline{w}(x')$ or $\underline{w}(x) \geq \bar{w}(x')$.

Assumption 1.3 is effectively an assumption that every change in state leads to a renegotiation of the wage. As will be shown in Section 1.2.3, this assumption holds when $\Delta \rightarrow 0$ for all but knife edge cases. With $\Delta > 0$, this assumption can be interpreted as an assumption that Δ is sufficiently small and that the various states differ sufficiently.

Strategy 1.1 1. *During bargaining, firms propose wage $\underline{w}(x)$, such that the worker is indifferent between accepting the wage or rejecting and making a counteroffer. Workers propose $\bar{w}(x)$, such that the firm is indifferent between accepting the wage or rejecting and making a counteroffer.*

2. *In state x , firms accept all wage offers $w \leq \bar{w}(x)$ and workers accept all wage offers $w \geq \underline{w}(x)$.*
3. *In state x , the worker opens renegotiation when $w < \underline{w}(x)$ and the firm opens renegotiation when $w > \bar{w}(x)$.*

Proposition 1.1 *Strategy 1.1 is a subgame perfect equilibrium.*

A proof of Proposition 1.1 can be found in Appendix B.

Given that the firm and the worker follow Strategy 1.1, consider a period in which the state is x and production takes place with wage w . Define $\pi^+(w, x)$ as the probability that, when a shock occurs, the state in the next period is one in which $\underline{w}(x') > w$. Define $\pi^-(w, x)$ as the probability that, when a shock occurs, the state in the next period is one in which $\bar{w}(x') < w$.

Value function $M_\Delta(w, x)$ is the value to a worker of working in state x with wage w for a given value of Δ . $J_\Delta(w, x)$ is the equivalent value function for firms.

$$\begin{aligned} M_\Delta(w, x) &= \Delta u(w) + \rho(1 - \psi)E[M_\Delta(w', x')] + \rho\psi E[U(x')] \\ J_\Delta(w, x) &= \Delta(p - w) + \rho(1 - \psi)E[J_\Delta(w', x')] + \rho\psi E[V(x')] \end{aligned}$$

where the expectations operators are as follows:

$$\begin{aligned} \rho(1 - \psi)E[M_\Delta(w', x')] &= \chi_x M_\Delta(w, x) \\ &\quad + \chi^+(w, x)E_{w,x}^+[M_\Delta(\underline{w}(x'), x')] \\ &\quad + \chi^-(w, x)E_{w,x}^-[M_\Delta(\bar{w}(x'), x')] \\ \rho(1 - \psi)E[J_\Delta(w', x')] &= \chi_x J_\Delta(w, x) \\ &\quad + \chi^+(w, x)E_{w,x}^+[J_\Delta(\underline{w}(x'), x')] \\ &\quad + \chi^-(w, x)E_{w,x}^-[J_\Delta(\bar{w}(x'), x')] \end{aligned}$$

Define probability parameters $\chi_x \equiv \rho(1 - \psi)(1 - \lambda(1 - \pi_x))$, $\chi^+(w, x) \equiv \rho(1 - \psi)\lambda\pi^+(w, x)$, and $\chi^-(w, x) \equiv \rho(1 - \psi)\lambda\pi^-(w, x)$.

Define conditional expectations operators $E_{w,x}^+ \equiv E_{x':\underline{w}(x')>w}$ and $E_{w,x}^- \equiv E_{x':\bar{w}(x')<w}$.

The recursive value functions may be rewritten:

$$M_{\Delta}(w, x) = \frac{\Delta u(w) + \rho(1 - \psi)E[M_{\Delta}(w', x')] - \chi_x M(w, x) + \psi E[U(x')]}{1 - \chi_x} \quad (1.1)$$

$$J_{\Delta}(w, x) = \frac{\Delta(p - w) + \rho(1 - \psi)E[J_{\Delta}(w', x')] - \chi_x J(w, x) + \psi E[V(x')]}{1 - \chi_x} \quad (1.2)$$

The indifference conditions for acceptance versus rejection of \underline{w} and \bar{w} follow.

$$M_{\Delta}(\underline{w}(x), x) = \Delta u(z) + \rho(1 - \delta_W)E[M_{\Delta}(\bar{w}(x'), x')] + \rho\delta_W E[U(x')]$$

$$J_{\Delta}(\bar{w}(x), x) = -\Delta\gamma + \rho(1 - \delta_F)E[J_{\Delta}(\underline{w}(x'), x')] + \rho\delta_F E[V(x')]$$

1.2.3 INSTANTANEOUS COUNTEROFFERS

Consider the implications of the strategy. First, I introduce simplified notation for the value functions. As $\Delta \rightarrow 0$, the wage, and hence the value function, does not depend on which party proposes. To reflect this, the value function representations drop the Δ subscript and are a function only of the state x .

$$M(x) \equiv \lim_{\Delta \rightarrow 0} M_{\Delta}(\bar{w}(x), x) = \lim_{\Delta \rightarrow 0} M_{\Delta}(\underline{w}(x), x)$$

$$J(x) \equiv \lim_{\Delta \rightarrow 0} J_{\Delta}(\bar{w}(x), x) = \lim_{\Delta \rightarrow 0} J_{\Delta}(\underline{w}(x), x)$$

Given this outcome, the value of being matched and producing in state x can be represented as the sum of three components. The first is the discounted value of receiving period utility (or profit) $u(w(x))$ over the expected duration of being matched in state x . The second component is the expected value of being matched once the state has changed, discounted according to the expected duration until the state changes. The third is the value of being unmatched, discounted according to the expected duration until the match breaks down.

Taking the limits as $\Delta \rightarrow 0$, the value functions are defined recursively by conditions (1.3) and (1.4).

$$M(x) = \frac{u(w(x)) + \ell(1 - \pi_x)E_{x' \neq x}[M(x')] + sE[U(x')]}{r + s + \ell(1 - \pi_x)} \quad (1.3)$$

$$J(x) = \frac{p - w(x) + \ell(1 - \pi_x)E_{x' \neq x}[J(x')] + sE[V(x')]}{r + s + \ell(1 - \pi_x)} \quad (1.4)$$

Proposition 1.2 *The subgame perfect equilibrium in Proposition 1.1 exhibits the following limiting properties:*

1. *In the limit as $\Delta \rightarrow 0$, firms and workers offer the same wage $w(x) \equiv \underline{w}(x) = \bar{w}(x)$, for any given x .*
2. *In the limit as $\Delta \rightarrow 0$, the equilibrium wage solves condition (1.5).*

$$\frac{u(w(x)) - u(z) + B_W[M(x) - U(x)]}{p - w(x) + \gamma + B_F[J(x) - V(x)]} = u'(w(x)) \quad (1.5)$$

Proof 1.2 Throughout, assume that workers and firms follow Strategy 1.1.

First, rewrite the indifference conditions as (1.6) and (1.7).

$$\begin{aligned} \Delta [u(\underline{w}(x)) - u(z)] &= \chi_x [M_\Delta(\bar{w}(x), x) - M_\Delta(\underline{w}(x), x)] \\ &\quad + \chi^+(\underline{w}(x), x)E_{\underline{w}(x), x}^+ [M_\Delta(\bar{w}(x'), x') - M_\Delta(\underline{w}(x'), x')] \\ &\quad - \rho(1 - \psi)\phi_W E[M_\Delta(\bar{w}(x'), x') - U(x')] \end{aligned} \quad (1.6)$$

$$\begin{aligned} \Delta [p - \bar{w}(x) + \gamma] &= \chi_x [J_\Delta(\underline{w}(x), x) - J_\Delta(\bar{w}(x), x)] \\ &\quad + \chi^-(\bar{w}(x), x)E_{\bar{w}(x), x}^+ [J_\Delta(\underline{w}(x'), x') - J_\Delta(\bar{w}(x'), x')] \\ &\quad - \rho(1 - \psi)\phi_F E[J_\Delta(\underline{w}(x'), x') - V(x')] \end{aligned} \quad (1.7)$$

Claim 1.2.1 *In the limit as $\Delta \rightarrow 0$, both firms and workers offer the same wage $w(x) \equiv \underline{w}(x) = \bar{w}(x)$.*

Proof 1.2.1 Begin by noting that

$$\lim_{\Delta \rightarrow 0} \chi^+(w, x) = 0, \forall x, \forall w \in [\underline{w}(x), \bar{w}(x)]$$

$$\lim_{\Delta \rightarrow 0} \chi^-(w, x) = 0, \forall x, \forall w \in [\underline{w}(x), \bar{w}(x)]$$

$$\lim_{\Delta \rightarrow 0} \phi_W = 0$$

$$\lim_{\Delta \rightarrow 0} \phi_F = 0$$

Taking the $\lim_{\Delta \rightarrow 0}$ of conditions 1.6 and 1.7 gives the following:

$$M(\bar{w}(x), x) = M(\underline{w}(x), x)$$

$$J(\underline{w}(x), x) = J(\bar{w}(x), x)$$

Applying conditions (1.1) and (1.2), I find that $\underline{w}(x) = \bar{w}(x), \forall x$. Define wage function $w(x)$ as this equilibrium wage as $\Delta \rightarrow 0$.

QED

Claim 1.2.2 *In the limit as $\Delta \rightarrow 0$, $w(x)$ satisfies condition (1.5).*

Proof 1.2.2 Take the ratio between (1.6) and (1.7).

$$\frac{\Delta(u(\underline{w}(x)) - u(z)) + \rho(1 - \psi)\phi_W E[M_\Delta(\bar{w}(x'), x') - U(x')]}{\Delta(p - \bar{w} + \gamma) + \rho(1 - \psi)\phi_F E[J_\Delta(\underline{w}(x'), x') - V(x')]}$$

=

$$\frac{\chi_x[u(\underline{w}(x)) - u(\bar{w}(x))] + \chi^+(\underline{w}(x), x) E_{\underline{w}(x), x}^+[u(\underline{w}(x')) - u(\bar{w}(x'))]}{\chi_x(\bar{w}(x) - \underline{w}(x)) + \chi^-(\bar{w}(x), x) E_{\bar{w}(x), x}^-[u(\underline{w}(x')) - u(\bar{w}(x'))]}$$

Allow $\Delta \rightarrow 0$. Note that as $\Delta \rightarrow 0$, the expected value of the state values in the next period is their current value.

$$\lim_{\Delta \rightarrow 0} E[M_\Delta(x')] = M(x)$$

$$\lim_{\Delta \rightarrow 0} E[U(x')] = U(x)$$

$$\lim_{\Delta \rightarrow 0} E[J_\Delta(x')] = J(x)$$

$$\lim_{\Delta \rightarrow 0} E[V(x')] = V(x)$$

$$\frac{u(w(x)) - u(z) + B_W[E[M(x')] - E[U(x')]]}{p - w(x) + \gamma + B_F[E[J(x')] - E[V(x')]]} = u'(w(x))$$

In the limit as $\Delta \rightarrow 0$, the equilibrium wage is characterized by condition (1.5).

QED

QED

As $\Delta \rightarrow 0$, bargaining is instantaneous and counteroffers are never made in the equilibrium. There is a single equilibrium wage in each state and its value does not depend on which agent proposes the wage. Although firms and workers can commence bargaining at any point, they do so only when the state changes. Firms initiate bargaining when it will lower the wage, and workers initiate bargaining when it will raise the wage.

1.3 NASH BARGAINING

In Nash (1950), the bargaining solution maximizes the product of the firm's and worker's surpluses. Allowing for asymmetric bargaining power, Nash's bargaining solution solves the following condition, where worker's bargaining power is $\beta \in [0, 1]$.

$$w^* = \operatorname{argmax}_w [\text{Worker's Surplus}(w)]^\beta \times [\text{Firm's Surplus}(w)]^{1-\beta}$$

Binmore et al. (1986) explore the links between alternating offers bargaining and Nash bargaining, and make a distinction between two kinds of outside options. In rejecting a proposed wage, firms/workers may incur some cost from delay (the foregone profit and wage), and may increase the risk that the match breaks down. In the former case, the relevant outside options that firms and workers have are the returns to not producing at any instant³: $-\gamma$ and $u(z)$. The related surpluses are $p - w + \gamma$

³I drop the scaling by the length of the relevant interval of time.

and $u(w) - u(z)$, the net benefit to production, in terms of flows. Accordingly, Nash's bargaining solution with symmetric bargaining power solves condition (1.8).

$$\frac{u(w) - u(z)}{p - w + \gamma} = u'(w) \quad (1.8)$$

If B_W and B_F are zero, that is, if prolonging bargaining does not increase the likelihood of the match breaking down, then the bargaining game equilibrium, condition (1.5), is equivalent to condition (1.8), the characterization of Nash bargaining over flow values.

Consider instead a bargain where rejecting a wage offer brings an increased risk that the match breaks down and there is no cost from delay. The relevant outside options that firms and workers have in this situation are the values of being in the unmatched state: $V(x)$ and $U(x)$. The related surpluses are $J(x) - V(x)$ and $M(x) - U(x)$, the net benefits from being matched in terms of state values. Given these surpluses, Nash's bargaining solution with worker bargaining power β solves condition (1.9).

$$\frac{\beta}{1 - \beta} \frac{M(x) - U(x)}{J(x) - V(x)} = u'(w) \quad (1.9)$$

Suppose that B_W and B_F are relatively large, that is, prolonging bargaining carries a significant risk that the match breaks down. Then the state values become more influential in determining the equilibrium wage and the relative effect of the cost from delay is diminished. In this situation, the bargaining game equilibrium condition (1.5) is approximately condition (1.10).

$$\frac{B_W}{B_F} \frac{M(x) - U(x)}{J(x) - V(x)} = u'(w) \quad (1.10)$$

1.3.1 RENEGOTIATION AND THE OUTCOME OF BARGAINING

In condition (1.5), both the numerator and the denominator of the left hand side are linear combinations of the flow surpluses and the surpluses in terms of state

values. The resulting bargaining outcome can be considered to be a hybrid of the two bargaining outcomes, with the relative weights determined by the discounting parameter r and the match breakdown parameters B_W and B_F .

The structure of condition (1.5) is similar to the equilibrium conditions derived in Trejos and Wright (1995), Shi (1995), and Brügemann and Moscarini (2010), all of which modeled one-time bargains. The relative weights on bargaining over flow values versus bargaining over state values are determined by the same parameters. Allowing for the possibility of renegotiation does not affect the importance of delay vs match breakdown in determining the equilibrium wage. Naturally, allowing for renegotiation does introduce wage dynamics into the outcome.

1.3.2 WORKER BARGAINING POWER

Conditions (1.9) and (1.10) imply condition (1.11), which defines the worker bargaining power β in terms of the increased risk of match breakdown due to bargaining. In models of wage bargaining that apply the Nash bargaining solution over state values, the worker bargaining power parameter is often treated as an exogenous parameter, either chosen somewhat arbitrarily⁴, or calibrated to match a desired equilibrium outcome. Endogenizing this parameter holds potential for improving the understanding of wage bargaining.

$$\beta = \frac{B_F}{B_W + B_F} \tag{1.11}$$

If the match breakdown parameters B_W and B_F can be measured empirically, it is possible to produce an estimate of the worker bargaining power parameter. As an illustrative example, consider the case where, while bargaining is ongoing, firms may encounter other workers and workers may encounter other vacancies. This is similar to

⁴Such as to satisfy the efficiency condition derived in Hosios (1990)

the bargaining game in Rubinstein and Wolinsky (1985). When one party encounters another match, they abandon the existing match with probability one⁵. While any probability between zero and one of abandoning the match is plausible, I assume that firms and workers always abandon the match, as this maximizes the values of B_W and B_F .

I further assume that bargaining workers (firms) encounter alternative vacancies (unemployed workers) at the same rate as searching unemployed workers (firms). Again, this results in the maximum plausible probability of the match breaking down during bargaining. Let f denote the probability that an unemployed worker meets with a firm during a single fixed unit of time. Let q denote the probability that a firm with a vacancy meets an unemployed worker.

Suppose that the firm has proposed a wage and the worker is deciding whether to accept the offer. If the worker rejects the wage offer, she runs the risk that the firm will find another worker and abandon the match. Similarly, if a firm rejects a proposed wage, it runs the risk that the worker will find another vacancy. These assumptions yield the following:

$$\begin{aligned}
 B_W &= q \\
 B_F &= f \\
 \beta &= \frac{f}{q + f}
 \end{aligned}$$

These series may be estimated from US data. I generate the data on the job-finding rate f according to the procedure in Shimer (2005). I estimate the vacancy-filling rate q by dividing the job-finding rate by labor market tightness, the ratio of vacancies to unemployed workers. Labor market tightness is estimated according to the procedure in Chapter 3. The data sources are summarized in Appendix A.

⁵This rules out multiparty wage bargains such as Bertrand competition between two workers for the same job, as in Coles and Muthoo (1998).

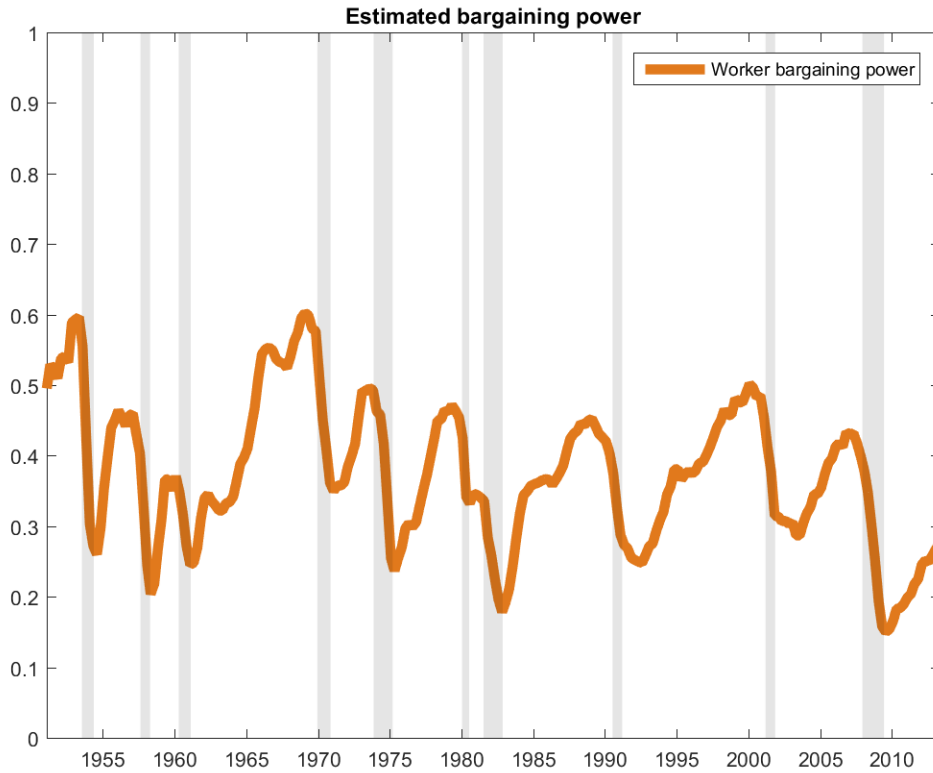


Figure 1.3: Values of worker bargaining power derived from match breakdown probabilities. Shaded areas indicate recessions.

Figure 1.3 gives the resulting estimate of worker bargaining power over time in the US. According to this result, bargaining power is procyclical, so that workers' share of the surplus from matching is larger during booms than during recessions. This is because booms are times when job offers arrive more frequently to workers and job applicants arrive less frequently to firms, with the reverse true during recessions.

In a study of models of job search with bargained wages and endogenous vacancy posting, Shimer (2005) shows that calibrating a model with the Nash bargain over

state values induces, relative to US data, excess volatility in wages and insufficient volatility in vacancies and unemployment. Shimer suggests that a model with countercyclical worker bargaining power may resolve this mismatch in volatility. However, this paper's derived endogenous worker bargaining power is procyclical and would worsen the mismatch. This suggests that fluctuating bargaining power is not a plausible avenue to resolving Shimer's puzzle, and provides evidence that bargaining over flow values may be more relevant than bargaining over state values.

1.4 CONCLUSION

This paper studies the outcome of bargaining in an ongoing productive relationship with renegotiation in a dynamic environment. While the bargaining environment is novel, the bargaining equilibrium is similar to outcomes in static environments. I derive a characterization of the resulting equilibrium wage which can be related to the two framings of the Nash bargain that are studied in Binmore et al. (1986). When the risk of match breakdown during bargaining is low, the bargaining outcome tends toward the Nash bargain over flow values. Alternatively, when the risk of match breakdown during bargaining is high, the bargaining outcome tends toward the Nash bargain over state values. I conclude with an analysis of the implications for worker bargaining power under the asymmetric Nash bargain over state values.

Before concluding, it is worthwhile to consider the theoretical implications of the bargaining outcome in condition (1.5). Similar results obtain in the monetary model of Shi (1995) and in Brügemann and Moscarini (2010). These papers study a one-time bargain, with no wage dynamics over time. The addition of renegotiation in a dynamic environment yields a similar analytic result, albeit one with wage dynamics as the state changes. This shows that the ability to renegotiate does not affect which type

of Nash bargain predominates in the outcome. Rather, it is the relative importance of the costs of delay versus the risk of match breakdown that determines the relevant surplus to be split. The ability to renegotiate affects how frequently the wage will change but not the determination of the wage, conditional on renegotiation.

CHAPTER 2

JOB SEPARATIONS AND THE CYCLICALITY OF UNEMPLOYMENT AND VACANCIES

2.1 INTRODUCTION

This paper studies the relative importance of job posting and job destruction in explaining the business cycle behavior of unemployment and job vacancies. Over the business cycle, unemployment and job vacancies exhibit large fluctuations, with strongly negative comovement, in what is called the Beveridge curve. I demonstrate that, in a labor search model calibrated to US data, productivity fluctuations alone do not replicate the observed comovement of unemployment and vacancies. Including the separation rate as a supplemental driving force allows the model to better match the relative volatility of unemployment and vacancies. I also document a change in the cyclical behavior of productivity and consider its implications for modeling labor search.

Shimer (2005) demonstrated that the canonical labor search and matching model with wage bargaining and endogenous vacancy posting does not match the observed volatility of unemployment and vacancies. In addition to drawing attention to the problem of modeling the labor market fluctuations, Shimer's work has introduced two practices that have frequently been applied in subsequent efforts, and that this paper argues can result in misleading conclusions. The first practice is to use the volatility of the ratio of vacancies to unemployment as the measure of labor market

fluctuations, rather than the behavior of the two series considered separately. The other is to consider only fluctuations in productivity as the driver of the model¹.

The rest of the paper proceeds as follows. In Section 2.2 I outline a basic model of labor search, matching, and vacancy posting. Analytical analysis of the model shows that productivity shocks affect vacancies and unemployment solely through the firms' vacancy-posting incentive, and induce movements along a single curve in the unemployment-vacancies space. The same is true of all shocks other than shocks to the matching parameters or the separation rate. Hence, only these shocks induce fluctuations in unemployment and vacancies that deviate from such a curve.

In Section 2.3 I calibrate the parameters and model the comparative statics with a fixed wage. I show that productivity shocks induce excessive fluctuations in vacancies relative to unemployment and that the separation rate is a potential driving force that can help the model match the comovement of unemployment and vacancies. I also document the changing cyclical nature of productivity, and show that there does not appear to be a similar change in the cyclical nature of the separation rate.

In Section 2.4 I simulate a search and matching model with a few wage specifications, and analyze the result. In early data, simulation with both productivity and separation rate shocks does well at matching cyclical outcomes. In more recent data, productivity is countercyclical and minimally correlated with the separation rate, and simulation requires strong assumptions to match the data.

¹Shimer actually considered both productivity and separation rate fluctuations in isolation, and found that only productivity fluctuations generated negative comovement between unemployment and vacancies.

2.2 CHARACTERIZING EQUILIBRIUM

In this section, I lay out a basic framework for determining the equilibrium level of unemployment and vacancies. The model begins with an overview of a basic search and matching model and an equilibrium condition for flows into and out of employment, the Inflow-Outflow curve. Together with the firm's Zero Profit condition, this curve determines the equilibrium value of unemployment and vacancies.

2.2.1 SEARCH, MATCHING, AND SEPARATION

Consider a mechanical model of search, matching, and separation. There is a stock of unemployed workers, denoted by u . Workers are either employed or unemployed, with the total stock of workers having mass 1. Consequently, the unemployment rate is also u , and the stock of employed workers is $1 - u$.

I assume that all unemployed workers search for an employer to match with and that firms post vacancies to match with workers. The stock of vacancies is denoted by v , and is equal to the number of vacancies per worker. The number of vacancies per unemployed worker, which I call labor market tightness, is denoted by θ . I use bar notation to indicate the steady state value of a variable.

Matching takes place according to a Cobb-Douglas matching function, so that the number of matches over a period is $\mu u^\alpha v^{1-\alpha}$. I refer to α as the matching elasticity parameter, and μ as the matching scale parameter. Dividing total matches by u or v , respectively, gives the job-finding rate f (2.1) and vacancy-filling rate q (2.2).

$$f = \mu \theta^{1-\alpha} \tag{2.1}$$

$$q = \mu \theta^{-\alpha} \tag{2.2}$$

In Section 2.3, I model the effect of shocks to the matching parameters. It will prove useful to define the matching scale parameter μ as the product of two components,

μ_1 and $\mu_2^{-\alpha}$. By setting $\mu_2 = \bar{\theta}^{-1}$, this ensures that when $\theta = \bar{\theta}$, fluctuations in α do not affect the job-finding rate.

$$\mu = \mu_1 \mu_2^{-\alpha} \quad (2.3)$$

Flows into unemployment are given by separations of existing matches². I denote the separation rate by s . The flows into and out of unemployment are given by $s * (1 - u)$ and $f * u$, respectively. The equilibrium level of unemployment is such that the inflow and outflow are equal, in condition (2.4).

$$s * (1 - u) = f * u \quad (2.4)$$

Solving out the job-finding rate, conditions (2.1) and (2.4) give condition (2.5), the graph of which is the Inflow-Outflow curve in Figure 2.1.

$$v = u^{\frac{-\alpha}{1-\alpha}} \left((1 - u) \frac{s}{\mu} \right)^{\frac{1}{1-\alpha}} \quad (2.5)$$

2.2.2 VACANCY POSTING

In order to match with a worker and produce, firms must post a vacancy, at per-period cost c . The probability of filling that vacancy in the current period is q , in condition (2.2). Once a firm has matched with a worker, they gain match output (or productivity) p and pay wage w each period. Firms and workers discount at rate r per period. The firm's value of being matched with a worker, denoted by J , is the discounted sum of the expected profits from the match, given by condition (2.6).

$$J = \sum_{\tau=0}^{\infty} \left(\frac{1-s}{1+r} \right)^{\tau} (p - w) \quad (2.6)$$

In equilibrium, labor market tightness is such that there is no expected profit from posting additional vacancies, which is the case when $qJ - c = 0$. Substituting

²With the assumption of no flow into/out of the labor force

Determination of labor market equilibrium

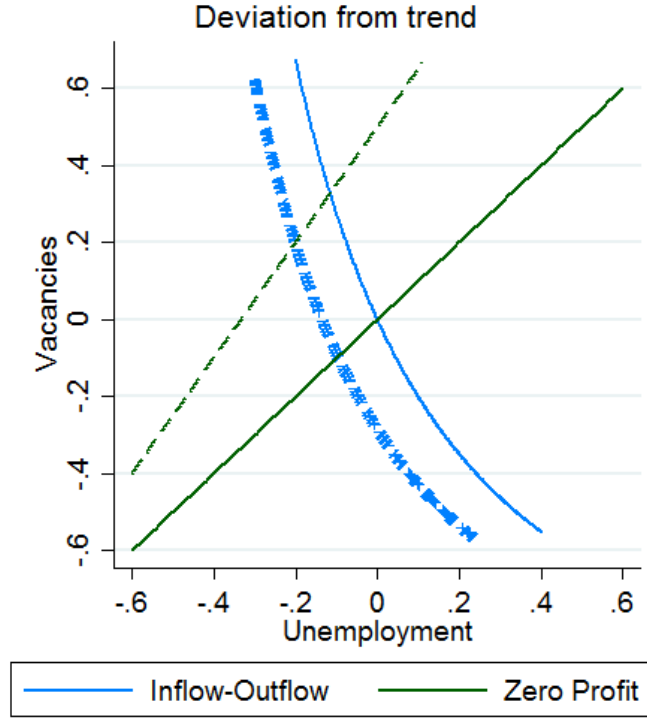


Figure 2.1: Determination of unemployment and vacancies by the Inflow-Outflow condition and the Zero Profit condition. Unemployment and vacancies are both depicted as deviations from trend value.

in condition 2.1, we get condition 2.7, the graph of which is the Zero Profit curve in Figure 2.1.

$$v = u \left(\frac{\mu J}{c} \right)^{\frac{1}{\alpha}} \quad (2.7)$$

2.2.3 DETERMINATION OF EQUILIBRIUM

The equilibrium of the labor market can be determined using two conditions, the Inflow-Outflow condition (2.5) and the Zero Profit condition (2.7). Figure 2.1 offers

a graphical representation. Consider, initially, that the Inflow-Outflow condition is represented by the solid curve and the Zero Profit curve is represented by the solid line. The resulting equilibrium is that both unemployment and vacancies are at their trend value.

Suppose a shock occurs which shifts the Zero Profit curve to the dashed line but does not shift the Inflow-Outflow curve. This could be due to a decrease in the wage w , the discount rate r , or the vacancy posting cost c , or it could be due to an increase in productivity p . The result is a movement along the Inflow-Outflow curve as firms increase their vacancy posting, which causes the unemployment rate to decrease and the vacancy rate to increase.

Suppose instead that a shock occurs which shifts the Zero Profit curve to the dashed line and shifts the Inflow-Outflow curve to the dashed curve. This could be due to a decrease in the separation rate s , an increase in the matching scale parameter μ_1 , or a change in the matching elasticity parameter α .

The essential insight from this framing of the labor market equilibrium is that, in the absence of any shocks that shift the Inflow-Outflow curve, unemployment and vacancies will fluctuate along the Inflow-Outflow curve. In particular, this means that a model that only considers shocks to productivity, wages, the discount rate, or the vacancy posting cost will generate movement along the Inflow-Outflow curve. Including shocks to the separation rate or to the matching parameters allows for equilibria that span the $u - v$ graph.

2.3 CALIBRATION AND SHOCKS

In this section I calibrate the model. The data used to do so are quarterly macro aggregates from the BLS spanning the years 1951 to 2013, described in Appendix

A. The vacancy data merit extra attention. There is not a single series of direct measurements of total vacancies in the US over a long duration. Furthermore, unlike with unemployment, there is not a common understanding of exactly what constitutes a vacancy.³ For this paper, I use the JOLTS measure where applicable, and for periods before the availability of JOLTS, I rescale the Conference Board’s Help Wanted Index (HWI), as compiled in Barnichon (2010).

Davis et al. (2013) raise issues of JOLTS undercounting vacancies by taking a sample of existing vacancies on a single day each month. Furthermore, this paper considers only job search from unemployment, ignoring job-to-job transitions and hiring, which may mean that JOLTS overestimates the vacancy postings relevant specifically to unemployed job searchers. I will set aside these issues and assume that the JOLTS vacancy estimate is an unbiased count of vacancies which could be matched with unemployed workers. This leads to an average vacancy-per-worker ratio of 0.567.

The remaining time series data, unemployment, the job-finding rate, and the separation rate, are generated according to the process specified in Shimer (2005). Much of the analysis in this paper uses detrended data, which is the ratio of the original data series to its HP-filtered trend. All data are HP-filtered with smoothness parameter $\lambda = 10^5$, again following Shimer. The use of such a high smoothness parameter is necessitated by the large cyclical fluctuations in vacancies and unemployment.

2.3.1 PRODUCTIVITY AND SEPARATION

I begin my model calibration by studying and modeling the two driving forces that I study in Sections 2.3 and 2.4. While data is available for all years from 1951 onward for

³While there is disagreement about which measure of unemployment is most relevant to different contexts, the definitions of the U1 to U6 unemployment measures are clear and commonly understood.

all relevant data series, there are potential issues with the productivity measure. As documented in Stiroh (2009), productivity was procyclical before 1984 and is countercyclical in more recent data. To account for any consequences from this development, I separately consider data from 1951Q1 to 1983Q4 and from 1984Q1 to 2013Q2. This allows for analysis of the effects of the changing cyclicity of productivity.

From regressing productivity on cyclical indicators, and applying the test in Andrews (1993) for a structural break in the parameters, it is clear that the cyclicity of productivity changes over the sample. The results of this analysis are summarized in Table 2.1, with the graph of the Andrews test Wald statistics in Figure 2.2. From 1951 to the mid 1980s, productivity is procyclical. The models estimate a parameter change for productivity around 1984, depending on the cyclical indicator. After the parameter change, productivity is countercyclical according to the labor market indicators of tightness and the unemployment rate and is acyclical according to GDP and NBER recession dates (the sum of the old and new parameters is not significantly different from zero). This change coincides roughly with the beginning of the Great Moderation, as identified by McConnell and Perez-Quiros (2000), although this may be coincidental.

A similar analysis with respect to the separation rate gives weaker results, suggesting a possible structural break in the early- to mid-1990s, but with very little evidence suggesting a change in the cyclicity of the separation rate. The results of the test for a structural break are given in Table 2.2 and Figure 2.3.

I generate a simulation of fluctuations of productivity alone, and of productivity and the separation rate together. The simulated results are presented in Section 2.4.2. To generate the former, I estimate an AR(1) model of the log of productivity. The results are given in Tables 2.3 and 2.4. I then apply the method of Tauchen (1986)

Table 2.1: Structural break regression to test for changing cyclical behavior of productivity

$$x_t = b_0 + b_p p_t + [b'_0 + b'_p p_t] I(t > t^*) + \epsilon_{x,t}$$

Cyclical indicator x	Estimated break date t^*	Wald statistic	p-value	Cyclicity post-break
Tightness*	1984Q1	32.4	0.000	Countercyclical
Unemployment rate	1986Q1	36.0	0.000	Countercyclical
log GDP	1984Q1	36.7	0.000	Acyclical
NBER recession	1983Q1	34.1	0.052	Acyclical

Productivity is procyclical before any break date. Cyclicity post-break refers to whether $b_p + b'_p$ is significantly different from zero, and the sign. The test for labor market tightness used a known-date test of parameter change.

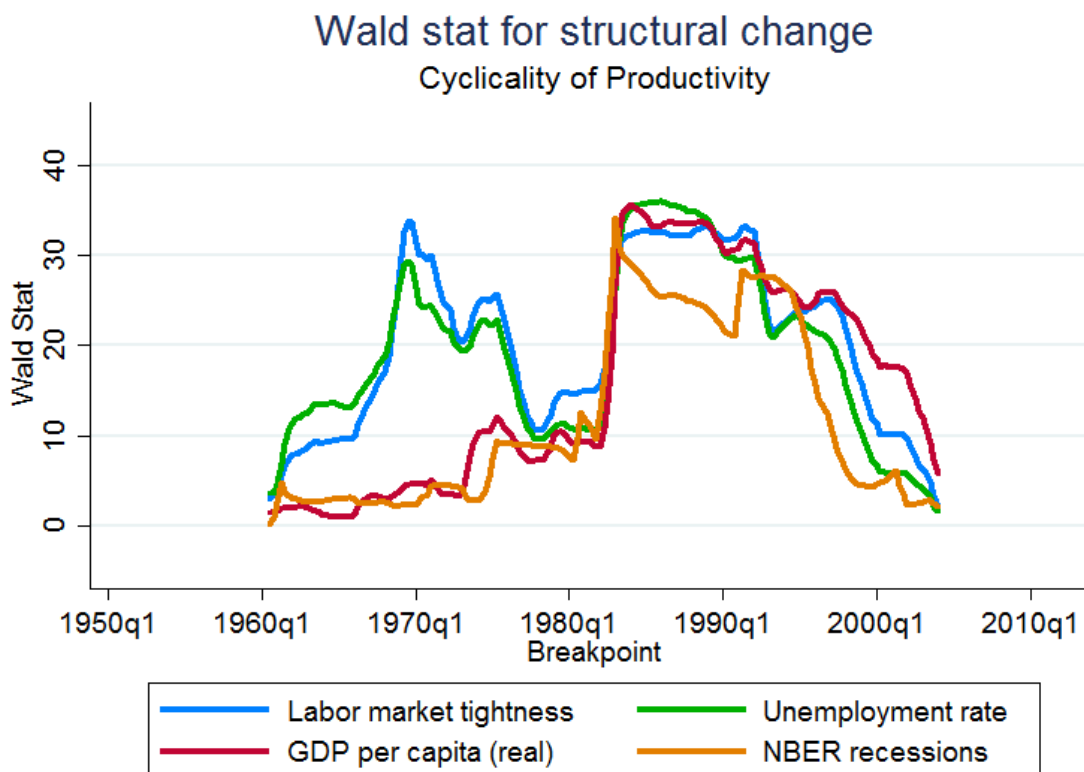


Figure 2.2: Wald statistic for structural break from regression of cyclical indicators on productivity.

Table 2.2: Structural break regression to test for changing cyclical behavior of separations

$$x_t = b_0 + b_s s_t + [b'_0 + b'_s s_t] I(t > t^*) + \epsilon_{x,t}$$

Cyclical indicator x	Estimated break date t^*	Wald statistic	p-value	Cyclicity post-break
Tightness	1994Q1	14.1	0.017	Countercyclical
Unemployment rate	1994Q1	12.6	0.033	Countercyclical
log GDP	1992Q1	7.6	0.236	Acyclical
NBER recession	1974Q4	12.4	0.035	Countercyclical

Separations are countercyclical before any break date. Cyclicity post-break refers to whether $b_s + b'_s$ is significantly different from zero, and the sign.

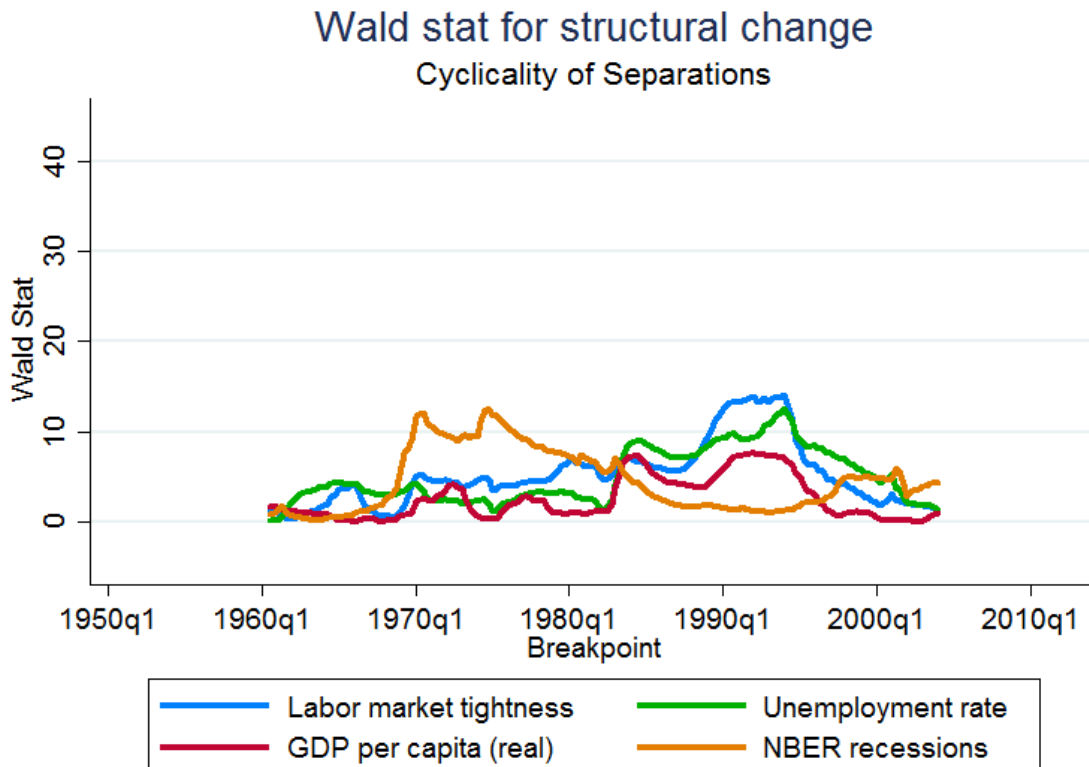


Figure 2.3: Wald statistic for structural break from regression of cyclical indicators on separations.

Table 2.3: AR(1) regression of log HP-filtered productivity, 1951-1983

$$\ln(p_t) = \text{constant} + \rho_p \ln(p_{t-1}) + \epsilon_t$$

Variable	Coefficient	(Std. Err.)
ρ_p	0.849	(0.046)
constant	0.000	(0.001)
N		131
R ²		0.72
F (1,129)		337.93
σ_ϵ^2		8.410×10^{-5}

Table 2.4: AR(1) regression of log HP-filtered productivity, 1984-2013

$$\ln(p_t) = \text{constant} + \rho_p \ln(p_{t-1}) + \epsilon_t$$

Variable	Coefficient	(Std. Err.)
ρ_p	0.942	(0.036)
constant	0.000	(0.000)
N		118
R ²		0.86
F (1,118)		683.85
σ_ϵ^2		3.941×10^{-5}

to generate a simulated set of 441 shocks to productivity, spanning three standard deviations.

In order to simulate the fluctuations in both productivity and separation rate, I model the comovement of the two series. I estimate a first-order VAR over productivity and the separation rate for each subsample. The estimation results are given in Tables 2.5 and 2.6. To simulate exogenous fluctuations in the model, I use the method of Tauchen (1986), with 21x21 states, distributed over three standard deviations of

shocks. Figures 2.5 and 2.7 illustrate the estimated distribution of contemporaneous realizations of productivity and separation rates. For comparison, I include the kernel density of the two variables in Figures 2.4 and 2.6.

One result is particularly striking. In the earlier subset of the data, productivity and the separation rate are negatively correlated, with procyclical productivity and a countercyclical separation rate. In the data from 1984-2013, productivity becomes countercyclical, and exhibits a weak positive correlation with the separation rate. The separation rate remains countercyclical. As productivity fluctuations are typically modeled as the driving force of cyclical fluctuations in search models of labor, this presents a challenge. It may be that productivity is not the primary driver of cyclical fluctuations in the labor market, or that the measurement of productivity is affected by changes in productive inputs across the business cycle.

Table 2.5: VAR(1) estimation of productivity and separations processes, 1951-1983 .

$$\begin{pmatrix} \ln\left(\frac{p_t}{p_{trend}}\right) \\ \ln\left(\frac{s_t}{s_{trend}}\right) \end{pmatrix} = A \begin{pmatrix} \ln\left(\frac{p_{t-1}}{p_{trend}}\right) \\ \ln\left(\frac{s_{t-1}}{s_{trend}}\right) \end{pmatrix} + \begin{pmatrix} \epsilon_{p,t} \\ \epsilon_{s,t} \end{pmatrix}$$

Variable	Coefficient	(Std. Err.)
$a_{1,1}$	0.856	(0.055)
$a_{1,2}$	0.002	(0.011)
$a_{2,1}$	-0.875	(0.341)
$a_{2,2}$	0.640	(0.069)
N		131
Log-likelihood		625.7951
$\hat{\Sigma}$	8.278×10^{-5}	-1.549×10^{-4}
	-1.549×10^{-4}	3.336×10^{-3}

Table 2.6: VAR(1) estimation of productivity and separations processes, 1984-2013

$$\begin{pmatrix} \ln\left(\frac{p_t}{p_{trend}}\right) \\ \ln\left(\frac{s_t}{s_{trend}}\right) \end{pmatrix} = A \begin{pmatrix} \ln\left(\frac{p_{t-1}}{p_{trend}}\right) \\ \ln\left(\frac{s_{t-1}}{s_{trend}}\right) \end{pmatrix} + \begin{pmatrix} \epsilon_{p,t} \\ \epsilon_{s,t} \end{pmatrix}$$

Variable	Coefficient	(Std. Err.)
$a_{1,1}$	0.923	(0.035)
$a_{1,2}$	0.032	(0.010)
$a_{2,1}$	-0.017	(0.223)
$a_{2,2}$	0.735	(0.063)
N		131
Log-likelihood		654.899
$\hat{\Sigma}$	3.565×10^{-5}	-1.898×10^{-5}
	-1.898×10^{-5}	1.463×10^{-3}

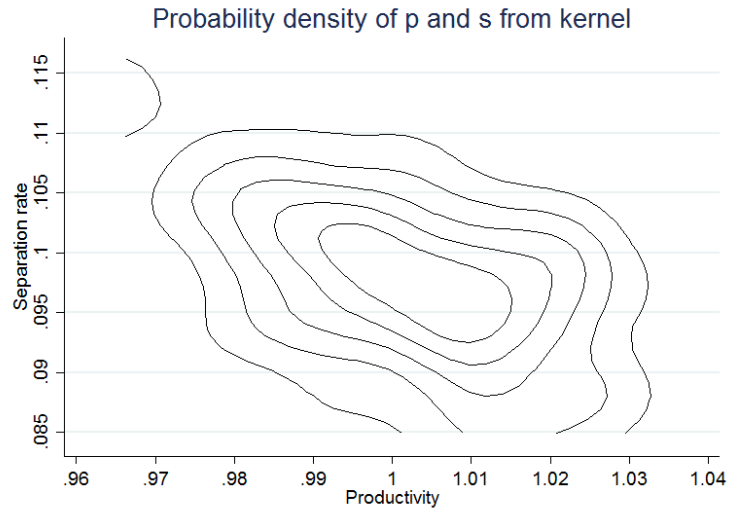


Figure 2.4: Kernel estimation of the probability density of realizations of productivity and the separation rate, from detrended data, 1951-1983. Productivity and the separation rate have a contemporaneous correlation of -0.55 .

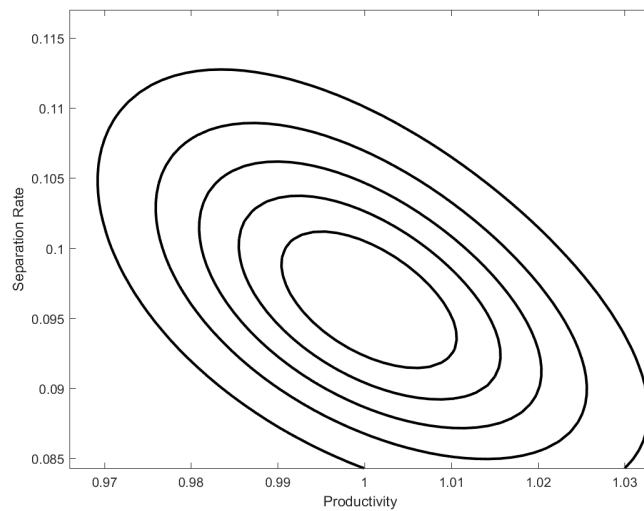


Figure 2.5: Graphical representation of the density of productivity and separation rate realizations estimated in Table 2.5. The negative correlation of the two series is evident in the negative slope of the primary axis of the contours.

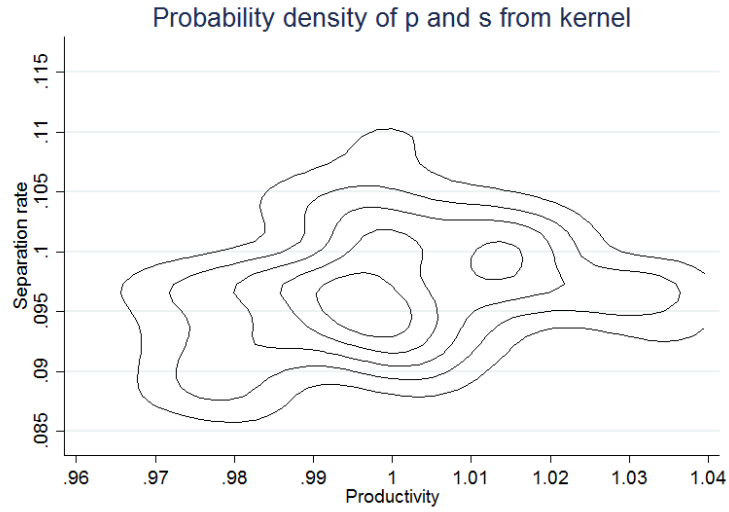


Figure 2.6: Kernel estimation of the probability density of realizations of productivity and the separation rate, from detrended data, 1984-2013. Productivity and the separation rate have a contemporaneous correlation of 0.17.

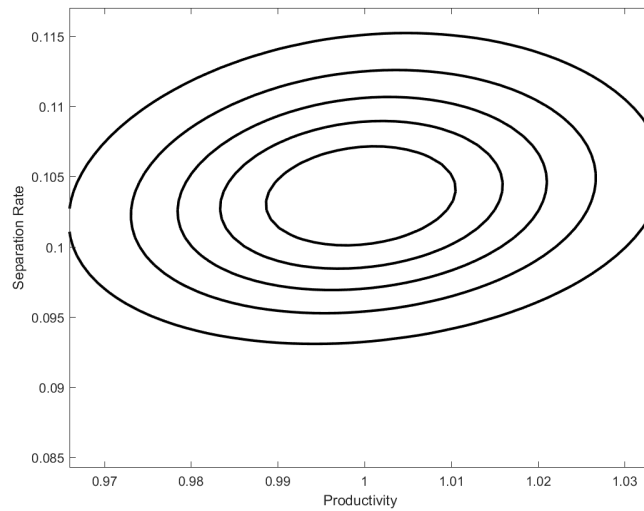


Figure 2.7: Graphical representation of the density of productivity and separation rate realizations estimated in Table 2.6. There is a weak positive correlation between the two series.

2.3.2 THE MATCHING FUNCTION

In this section I calibrate the matching function and apply the calibrated parameter values into the Inflow-Outflow condition. To do so, I graph the Inflow-Outflow curve generated by condition (2.5), treating the separation rate s and the matching parameters α and μ as constant. This requires estimates of the values of these parameters. While the simulations in Section 2.4 will be studied for the two subsamples of data laid out in the previous Section, an analysis of the entire dataset will suffice for comparing the Inflow-Outflow curve to the data.

I set the value of the separation rate as its average value in the data, which is $\bar{s} = 0.0975$. This average value does not change much in the subsamples, taking values of 0.1039 and 0.0968 in the earlier and later subsamples.

The Cobb-Douglas matching elasticity parameter α can be estimated using data on the job-finding rate f and labor market tightness θ . Taking logs of condition (2.1) and adding an error term, I get a condition that is linear in α , which I estimate by OLS. In order to avoid issues stemming from cyclical fluctuations in the measurement of the job-finding rate or labor market tightness, I run the estimation using the cyclical component of $\ln(f)$ and $\ln(\theta)$.

The estimation result is given in Table 2.7, with the resulting estimate of $\alpha = 0.678$. For the earlier subsample, the estimate is 0.708, and the estimate is 0.622 for the later subsample. Figure 2.8 shows the result of applying this estimation over rolling 20 year windows. The resulting estimate is fairly stable until around the year 1990. This decline in the estimate of α roughly coincides with the transition from the Conference Board's HWI vacancy index to the BLS' JOLTS index, suggesting that there may be some concern with comparability of the HWI and JOLTS measures of vacancy posting. I set this issue aside and use the estimated value of α , as the

Table 2.7: Estimating the matching elasticity parameter

$$\ln(f_t) = \text{constant} + (1 - \hat{\alpha})\ln(\theta_t) + \epsilon_t$$

Variable	Coefficient	(Std. Err.)
$1 - \hat{\alpha}$	0.322	(0.007)
constant	0.000	(0.003)
N		250
R ²		0.885
F _(1,248)		1907.41

Data are detrended

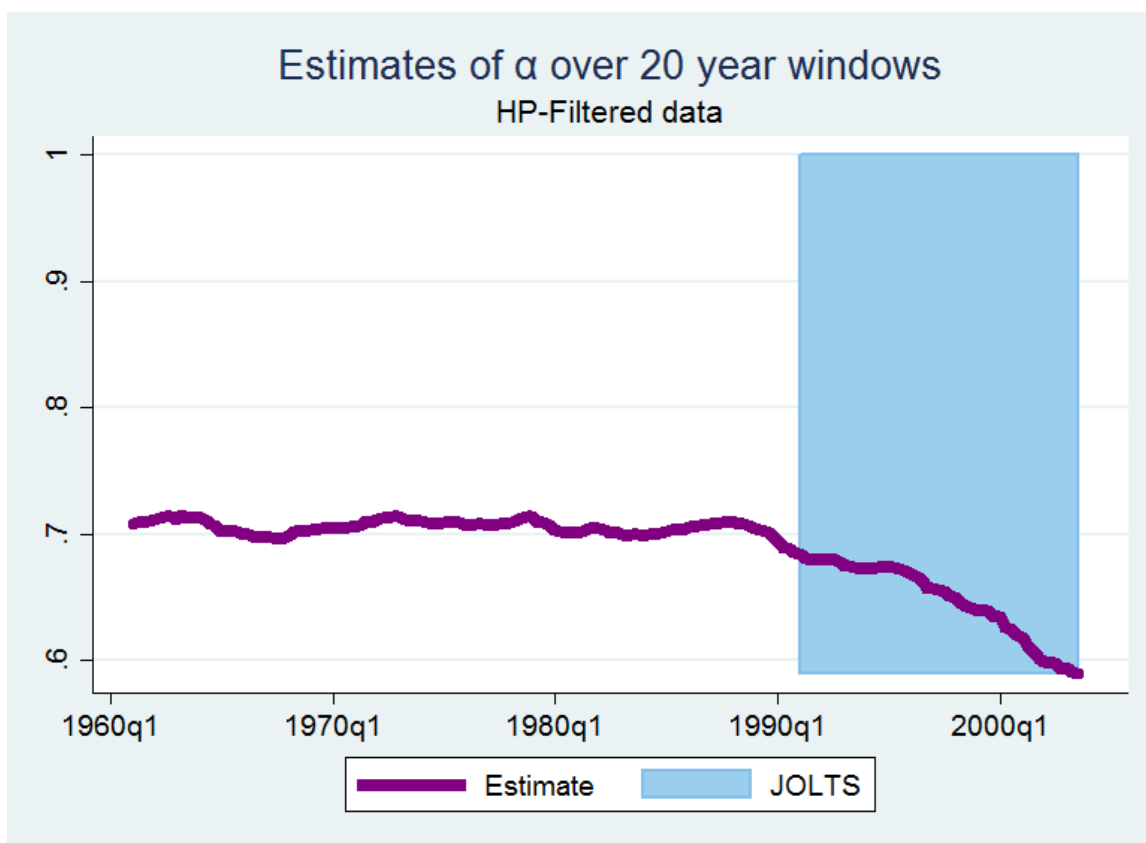


Figure 2.8: Rolling estimates of the matching elasticity parameter

Table 2.8: Parameter and steady state values over subsamples of the data

Estimate	1951-2013	1951-1983	1984-2013
$\bar{\theta}$	0.567	0.632	0.495
\bar{s}	0.0975	0.1039	0.0968
α	0.678	0.708	0.622
μ	1.543	1.517	1.592
μ_1	2.267	2.099	2.139

estimated value is only somewhat smaller than its more stable estimate from the older data.

The estimated value of α is on the high end of recent estimates using JOLTS data. Borowczyk-Martins et al. (2013) argue that estimates of α may be biased upward by endogeneity, and obtain a lower estimate with an IV estimation over unfiltered data. Sedláček (2016), however, corrects for search by the already-employed, and obtains estimates similar to the values in this paper.

Given the estimated value of the matching elasticity parameter and the average values of labor market tightness and the job-finding rate, I estimate the matching scale parameter μ using condition (2.1) in the steady state, with resulting estimate $\mu = 1.543$. The estimates are 1.517 and 1.592 for the older and more recent subsamples, respectively. Table 2.8 summarizes the estimated parameter values and mean observations that will be relevant for calibration.

I consider whether the observed fluctuations in unemployment and vacancies can be generated by fluctuations along the Inflow-Outflow curve alone. First, I graph unemployment and vacancies in terms of deviations from trend, using full series of data from 1951 to 2013. This is the scatter plot in Figure 2.9. To model the comovement

Table 2.9: Estimating elasticity of vacancies with respect to unemployment

$$\ln(v_t) = \text{constant} + \text{elasticity} \ln(u_t) + \epsilon_t$$

Variable	Coefficient	(Std. Err.)
elasticity	-0.909	(0.028)
constant	0.000	(0.005)
N		250
R ²		0.807
F _(1,248)		1040.1

Data are HP-filtered

Comovement of unemployment and vacancies

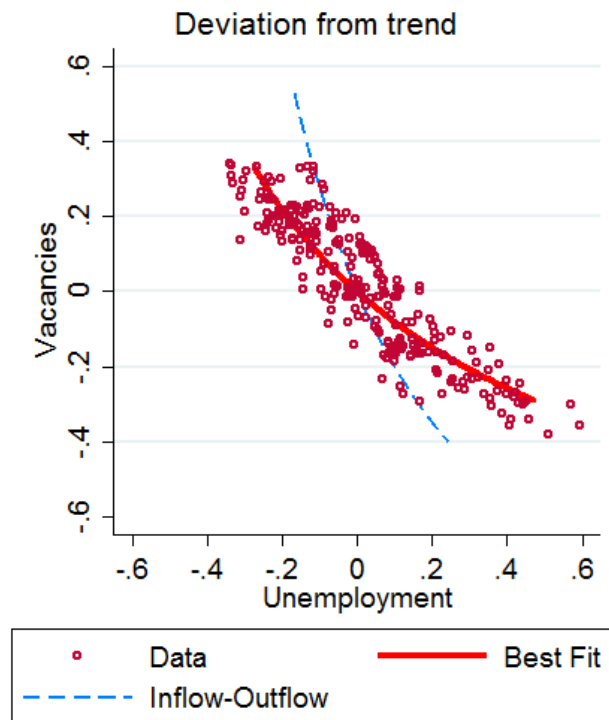


Figure 2.9: Fluctuations in vacancies and unemployment from data and the Inflow-Outflow curve. The lines span two standard deviations of observed labor market tightness.

of these two series, I estimate a constant elasticity model for u and v , with the results in Table 2.9. The Best Fit curve is the graph of the curve described by the estimation results. The end points of the Best Fit Curve are the 2.5th to 97.5th percentiles of labor market tightness in the data.

The steeper curve in Figure 2.9 is the Inflow-Outflow curve, the set of values of unemployment and vacancies that result from fluctuations in productivity alone. This curve is generated by applying the estimated parameter values and mean separation rate (from the full sample) in condition (2.5). As with the Best Fit curve, the Inflow-Outflow curve spans the 2.5th to 97.5th percentiles of labor market tightness in the data.

Fluctuations in vacancy posting alone result in excessive fluctuations in the vacancy rate relative to the unemployment rate. In order to successfully match the data, a model will need to include fluctuations in a variable that generates a different curve in the u - v space. The intuitive candidate is one that generates a less steep curve that is still negatively sloped, and is correlated with the shocks driving labor market fluctuations through posting alone.

It is of course possible to match the observed comovement with a linear combination of any two curves. However, generating such behavior with a steep or positively sloped curve would require large, wide dispersion along the two curves and a very high correlation between the two driving factors. In prior research⁴, models have generally shown that the commonly applied driving factor of productivity does not generate large fluctuations along the posting-only curve, relative to the observed fluctuations. This suggests that the best candidate for a second driving factor is one generating a

⁴Shimer (2005) or Hall and Milgrom (2008), for example. Hagedorn and Manovskii (2008) closely match the observed fluctuations.

curve in the $u-v$ space with a negative slope that is less steep than the Inflow-Outflow curve.

There are three parameters remaining to calibrate in the steady state: the discount rate r , the vacancy posting cost c , and the equilibrium wage w . I set the discount rate so that a period is one month. This results in discount rate $r = 0.012$. I calibrate the remaining parameters to fit calibration criteria in the steady state, when the separation rate is \bar{s} , labor market tightness is $\bar{\theta}$, and productivity is $\bar{p} = 1$.

The vacancy posting cost is calibrated to match the findings of Silva and Toledo (2009), who find that hiring costs are, on average, equal to 14% of quarterly compensation costs. This is a direct measure of the time cost of managerial labor devoted to hiring. Hagedorn and Manovskii (2008) suggest an additional cost of capital that sits idle until the hire is completed. I follow both of these formulations, with calibration given by equation (2.8). Solving conditions (2.6) and (2.8) gives values $c = 0.570$ and $w = 0.973$.

$$c = \bar{q} * 0.14 * w + 0.471 * \bar{p} = 0.570 \tag{2.8}$$

2.4 SIMULATION

As a first consideration of the wage mechanism, I assume that the wage is the same in every state of the world. Thus, when shocks hit, the wage does not change. While this property is not realistic, it is useful for analytical analysis, as it does not require a model of wage dynamics to study the implications of shocks to the search model. I apply conditions (2.5), (2.6), and (2.7) to solve for the labor market equilibrium. I derive and analyze comparative statics from search and matching parameter changes to investigate the potential of different shocks to induce fluctuations in unemployment

and vacancies like those observed in the data. In the next section, I simulate the model subject to shocks to productivity and the separation rate.

2.4.1 FIXED WAGE

For comparative statics, I investigate the effect on the steady state model of shocks. The shocks are to parameters that are found in the Inflow-Outflow condition (2.5). These parameters are the matching scale parameter and the matching elasticity parameter, as well as the separation rate. I have not specified whether the change in parameter value analyzed in the comparative statics is permanent or transitory. For fluctuations of the matching parameters, the persistence of the change does not matter. Changes to the matching function affect the cost-versus-profit motive for posting a vacancy, but once the vacancy is filled, the profit from the match is the same regardless of the values of μ and α .

However, for the separation rate, the persistence of the shock to s matters, as a firm's willingness to post a vacancy depends on the expected duration of the match. I consider two possibilities, first where fluctuations are a one-time deviation from s , denoted by \tilde{s} . With a 1-time deviation in s to \tilde{s} , $\tilde{J} = (p - w) \frac{1+r+s-\tilde{s}}{r+s}$. For the second, where fluctuations in s are permanent, no \sim -notation is necessary.

Table 2.10 contains the comparative statics that result from shocks to the matching parameters and the separation rate. Each of the candidate parameter fluctuations generates the desired reduction in slope in the $u - v$ graph.

Figure 2.10 shows that fluctuations in the matching and separation parameters generate a curve in the $u - v$ space that is less steep than that from posting alone. Fluctuations in the matching parameters generate curves with very little fluctuation in vacancy posting relative to fluctuation in unemployment, as do permanent fluctuations in the separation rate. Transitory fluctuations in the separation rate induce

Fluctuations in parameters

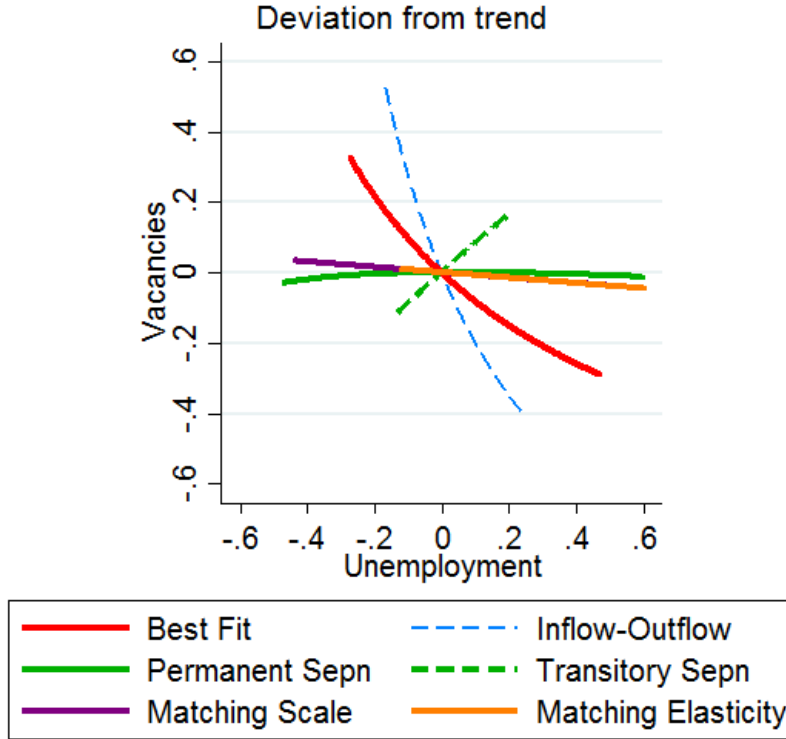


Figure 2.10: Fluctuations in vacancies and unemployment from data and from various shocks. The Best Fit and Inflow-Outflow curves are the same as Figure 2.9. Shocks to the matching parameters and permanent shocks to the separation rate result in the flat curves, with minimal effects on vacancy posting. Transitory shocks to the separation rate result in a curve with a positive slope.

Table 2.10: Comparative statics from shocks to matching parameters and the separation rate

Shock	Slope	Comparison to Inflow-Outflow
p	$-\theta^\alpha \frac{s}{\mu} \left(1 + \frac{\alpha}{1-\alpha} u^{-1}\right)$	
s	$-\theta^\alpha \frac{\tilde{s}}{\mu} \left(1 + \frac{\alpha}{1-\alpha} u^{-1}\right) + \frac{\alpha}{1-\alpha} \frac{\theta}{1-u} \frac{r+s}{s+\alpha r}$	Less steep
\tilde{s}	$-\theta^\alpha \frac{\tilde{s}}{\mu} \left(1 + \frac{\alpha}{1-\alpha} u^{-1}\right) + \frac{\alpha}{1-\alpha} \frac{\theta}{1-u} \frac{1+r+s-\tilde{s}}{s+\alpha(1+r-\tilde{s})}$	Less steep
μ_1	$-\theta^\alpha \frac{s}{\mu} \left(1 + \frac{\alpha}{1-\alpha} u^{-1}\right) + \frac{\alpha}{1-\alpha} \frac{\theta}{1-u} \frac{1}{\alpha+\mu_1-\alpha\mu_1}$	Less steep
α	$-\theta^\alpha \frac{\tilde{s}}{\mu} \left(1 + \frac{\alpha}{1-\alpha} u^{-1}\right) + \frac{\alpha}{1-\alpha} \frac{\theta}{1-u} \frac{r+s}{s+\alpha r}$	Less steep

positive comovement between unemployment and vacancies, leaving their ratio virtually unchanged.

While both of the matching parameters have potential, the rest of this analysis will focus on fluctuations in the separation rate. In addition to its effect on unemployment, the separation rate has other desirable properties that the matching parameters lack. The separation rate is derived directly from the data, and is available at a monthly frequency. The matching elasticity parameter α is estimated by regression, and can not be measured at quarterly or monthly frequency. The matching scale parameter μ_1 is imputed from the steady state, and not observed directly.

2.4.2 FLEXIBLE WAGES

In this section, I simulate the model with separation rate and productivity fluctuations, and compare the results to the Best Fit curve from the data, and to a calibrated Inflow-Outflow curve⁵. I graph the results for three specifications: a fixed wage, a wage that varies with productivity according to constant elasticity $\eta = 0.5$, and a wage that varies according to a constant elasticity calibrated to best match the Best Fit curve.

The constant elasticity wage rules follow condition 2.9. Under this specification, wages fluctuate with a constant elasticity η with regard to productivity.

$$w(p, s) = w_{ss} * \left(\frac{p}{\bar{p}}\right)^\eta \tag{2.9}$$

In order to simulate the model, I use the previously constructed series of productivity and separation rate realizations, and determine a wage for each state according to condition 2.9. I use this result to estimate the value of J , a filled vacancy, in every state. I then estimate equilibrium labor market tightness in every state, and solve condition 2.5 for u and v . I then use OLS over log deviations from steady state to

⁵Fixed wage, no separation rate shocks.

estimate a line of best fit. I then find the standard deviation of the log of generated values of labor market tightness, and plot the outcomes within two standard deviations.

The constant wage model holds when $\eta = 0$. I choose to simulate the model under $\eta = 0.5$ because under this specification, when productivity changes, firms and workers share the change in the surplus evenly, as w_{ss} is close to \bar{p} . For the calibrated wage elasticity, I simulate the model for 101 evenly spaced values of η from zero to one. For each simulation, I regress a log-log model for u and v , and compare the parameter to that of the Best Fit line. I also find the standard deviation of log labor market tightness to measure dispersion of unemployment and vacancies. I then select as the calibrated model the value of η that minimizes the sum of the squared percent deviations from the values for the Best Fit line.

The graphs of the simulations are presented in Figures 2.11 and 2.12. For the data from 1984-2013, the constant wage model and the Inflow-Outflow curve span a much larger area, so I present a truncated graph.

The results of this simulation are depicted in Tables 2.11 and 2.12. In both subsamples, the Inflow-Outflow graph results in excessive fluctuations in vacancy posting relative to unemployment. For the data from 1951-1983, the Constant Wage model approximates the Best Fit curve reasonably well, in terms of both elasticity and volatility. The Calibrated model does even better. With a relatively inflexible wage (η is near zero), changes in productivity primarily go to the firm, leading to large effects on vacancy posting. The driving forces seem well-suited to fit a model to the data. With the negative correlation between the separation rate and productivity, adding fluctuations in the separation rate to the model has a large effect on the slope, even with large effects from productivity.

Calibrated fluctuations

Deviation from trend

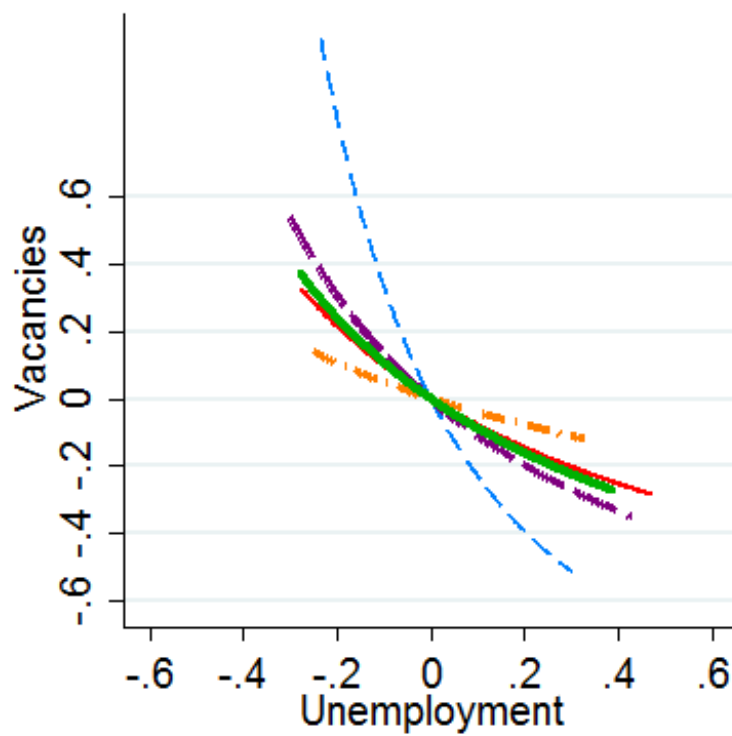


Figure 2.11: Fluctuations in vacancies and unemployment from data and from simulations, 1951-1983. The lines depict results spanning the 2.5th to 97.5th percentiles of the HP-filtered data series.

Calibrated fluctuations

Deviation from trend

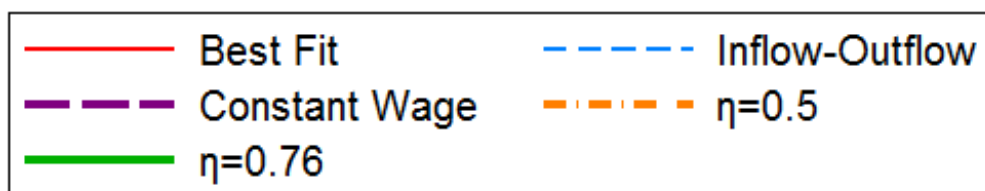
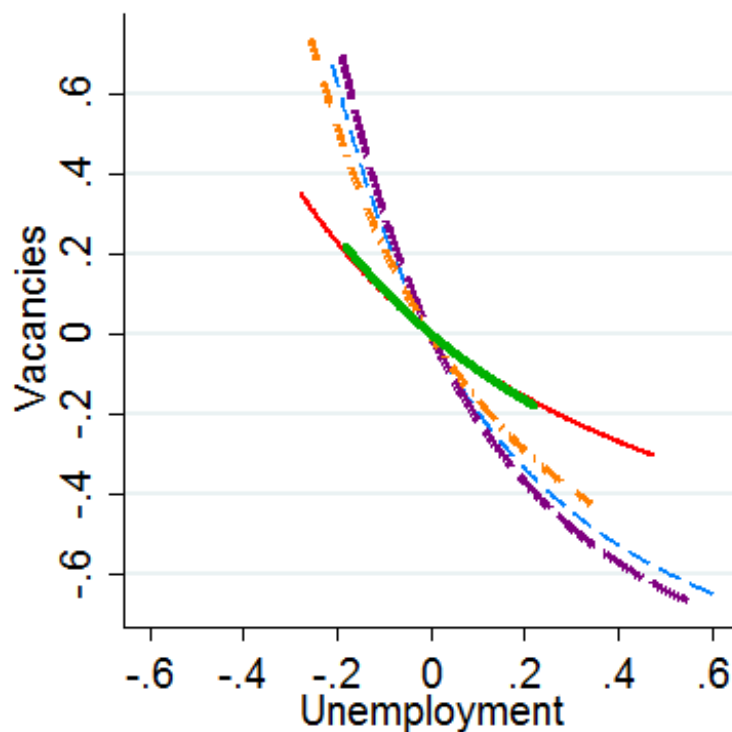


Figure 2.12: Fluctuations in vacancies and unemployment from data and from simulations, 1984-2013. The lines depict results spanning the 2.5th to 97.5th percentiles of the HP-filtered data series. Note that the graphs of the Constant Wage and Inflow-Outflow curves have been cropped to fit the window.

Table 2.11: Comparison of simulations to data, 1951-1983

Model	Elasticity v, u	$SD(\log(\theta))$
Best Fit	-0.869	0.410
Inflow-Outflow	-2.728	0.496
Constant Wage	-1.204	0.393
$\eta = 0.5$	-0.449	0.206
$\eta = 0.18$	-0.966	0.322

Table 2.12: Comparison of simulations to data, 1984-2013

Model	Elasticity v, u	$SD(\log(\theta))$
Best Fit	-0.929	0.320
Inflow-Outflow	-2.208	0.864
Constant Wage	-2.507	1.484
$\eta = 0.5$	-1.870	0.424
$\eta = 0.18$	-0.991	0.199

For the latter data, the differences in the graph highlight both the importance of the separation rate and the concerns with the productivity data. The most obvious results are that the Inflow-Outflow curve and the Constant Wage curve exhibit very large fluctuations. This is because the productivity fluctuations have a large effect on unemployment and vacancies given their behavior. When $\eta = 0.5$, which is to say, when workers and firms share evenly any change in productivity, the graph has a similar curvature, although with less volatility. This indicates that the separation rate fluctuations are insufficient to have much effect on the slope of the curve when they are weakly correlated with productivity shocks. Only when the wage is very flexible

($\eta = 0.76$) and productivity fluctuations have little effect on the firm's surplus does adding separation rate fluctuations have much effect on the slope of the curve.

With a value of $\eta = 0.76$, the calibrated model implies a very flexible wage. When productivity changes, most of the change goes into the wage. When considered with the fact that productivity is countercyclical from 1984-2013, this outcome raises concerns about using productivity as the driving force of vacancy posting in models of search and matching for the labor market.

2.5 DISCUSSION

Mortensen and Nagypal (2007) offer an alternative calibration of the matching function to that in Section 2.3.2. They treat the matching and separation parameters (μ, α, s) as constants, and calibrate matching elasticity α to match the graph of u and v induced by condition (2.5) to the cyclical behavior of unemployment and vacancies. However, this method of calibration suffers from omitted variable bias, as fluctuations in the matching and separation parameters will bias the estimate of matching elasticity, particularly if the fluctuations correlate with fluctuations in productivity or other relevant variables affecting vacancy-posting behavior. In effect, the estimation of Mortensen and Nagypal directly attributes all fluctuations in unemployment to vacancy posting.

Several authors have interpreted Mortensen and Nagypal's work to imply that adding separation rate fluctuations will only serve to increase the volatility of labor market tightness. Ironically, Mortensen and Nagypal are an exception in that they include separation rate fluctuations as a driving force in their model. Unfortunately, they do not seem to account for the negative correlation between productivity and the separation rate. The effect of adding separation rate shocks to a model is thus

primarily to adjust the slope of the graph in the $u - v$ space to more closely match the data, without much impact on the volatility of labor market tightness.

2.6 CONCLUSION

The goal of this paper is to document two oft overlooked issues in modeling wage bargaining, job market search frictions, and Shimer's puzzle. The first is that separation rate shocks are important to consider when assessing a model of unemployment and vacancies. With a calibrated matching function, a model that is driven only by productivity shocks will not be able to match the behavior of unemployment and vacancies. This model instead results in excessive fluctuations in vacancy posting relative to fluctuations in unemployment. Furthermore, because separation rate shocks are correlated with productivity shocks, adding separation rate shocks into the model will alter the relative volatilities of vacancies and unemployment, and not simply increase the volatility of labor market outcomes.

The second issue is that labor market tightness on its own is not a sufficient metric to evaluate a model's success in reproducing observed labor market volatility. It is important to consider separately a model's implications for unemployment and vacancies individually.

I find that there is some concern that productivity, at least as measured and reported by the Bureau of Labor Statistics, is worrisome as a primary driver of business cycle labor market behavior. Given how well it works in the earlier dataset, I suggest that future research may consider applying a measure of labor productivity that better accounts for cyclical fluctuations in productive inputs.

CHAPTER 3

WAGE BARGAINING AND THE BEVERIDGE CURVE

3.1 INTRODUCTION AND RELATED LITERATURE

In this paper I propose a new framing of the bargain between workers and firms when setting wages, in which they bargain over the flow surplus from production. This is a change from the standard formulation in the search and matching literature with wage bargaining, where workers and firms bargain over the surplus from the entire duration of the match. I embed this Nash wage bargain over flow values into a model of labor search and matching with endogenous vacancy posting, subject to shocks. Simulating the resulting equilibrium, the model is better able to match the business cycle aspects of the Beveridge curve than other wage bargains. Furthermore, I demonstrate through calibrated simulations that separation rate shocks and productivity shocks are essential to match the business cycle comovement of unemployment and vacancies, in contrast to earlier work which focused on productivity shocks alone.

It has been shown that search frictions provide a theoretically intuitive explanation for equilibrium unemployment. Within models of search in the labor market, there remains the question of how wages are determined. If labor sales take place not in a Walrasian market, but under a one-to-one relationship, the economist's standard solution of setting marginal cost equal to marginal benefit may not determine the wage.

A popular model of wage determination is one in which firms post wages. Burdett and Mortensen (1998) have an equilibrium search model with wage dispersion generated by wage posting and on-the-job search. Albrecht and Axell (1984) have a model of wage posting without on-the-job search, where wage dispersion is instead generated by heterogeneity among worker preferences for leisure. Van den Berg and Ridder (1998) estimate a model of wage posting with on-the-job search and firm heterogeneity.

On the other hand, Hall and Krueger (2012) find in a survey of US workers that about one third of respondents reported an explicit bargain over wages upon being offered their current job, while one third reported that they knew the exact wage prior to receiving the job offer. For the remaining third of workers, the wage may have been set as the outcome of an implicit bargain, where the offered wage was equal to that which would have been the outcome of bargaining.

An implicit assumption in the wage-setting of the preceding papers is that firms and workers can commit to a wage (or a schedule of wages). An environment where wages are set by wage-posting requires some mechanism to prevent firms or workers from attempting to change the wage. This assumption may be particularly problematic if wages vary contractually with productivity. If firms and workers both observe productivity (say of an individual), but can not credibly communicate it to the body tasked with enforcement of the wage contract, then that contract can not be enforced. Ultimately the wage would be determined by what workers and firms can credibly commit to. In most jobs, wages change over time to compensate for inflation, in response to improvements in productivity, or to reward and retain highly productive workers. These are situations that require a wage-setting mechanism that adjusts over the duration of the job.

Diamond (1982) first proposed Nash bargaining as a way of endogenizing wages. This method is applied in Mortensen and Pissarides (1994) to a model of the labor market with aggregate productivity shocks. Much subsequent work has used this formulation of the Nash bargain as a wage-setting mechanism. In these papers, firms and workers bargain over the surplus created over the duration of the match, with the outside option (or threat point) of dissolving the match. This paper will refer to such a framework as bargaining over state values. Calibrating these models to job-finding rates and unemployment levels results in high, elastic wages (close in value to productivity), and hence low variability in vacancy posting by firms relative to observed vacancy posting.

Shimer (2005) observes this counterfactual prediction of low volatility of vacancy posting in models of wage bargaining and endogenous vacancy posting. Several papers have proposed mechanisms to generate higher volatility. Hagedorn and Manovskii (2008) give a concise description of the problem from a modeling standpoint. In order for vacancy posting to fluctuate, firm profits per match must exhibit large fluctuations relative to the average value over the business cycle. This requires both that the average wage be close to average productivity, and that there be little fluctuation in the wage as productivity varies.

Hagedorn and Manovskii go on to propose a model of Nash bargaining over state values with two features. Workers have a very high flow value of unemployment (95.5% of average productivity, as opposed to 40% in Shimer's model), which ensures that the average flow profit from a match is close to zero. Firms gain the majority of the surplus from matches (firms have high bargaining power). This generates strongly procyclical profits.

Others have proposed reconsidering the mechanism by which wage bargaining takes place. Hall and Milgrom (2008) propose a model of alternating wage offers

between firms and workers (henceforth AO bargaining), at the rate of an offer per day. In terms of theory, the Nash bargain over flow values can be thought of as a similar model to Hall and Milgrom's, where offers instead arrive instantaneously, and with no increased risk of match breakdown during bargaining.

I also consider models where bargaining takes place according to the mechanism in Kalai and Smorodinski (1975) (henceforth KS bargaining). Nash bargaining divides a convex surplus space according to the axioms of scale invariance, Pareto optimality, symmetry (relaxed for asymmetric Nash bargains), and independence of irrelevant alternatives (IIA). KS bargaining replaces IIA with monotonicity.

Finally, I consider the role of risk aversion in bargaining. In Mortensen and Pissarides, the risk neutrality of consumers is considered an approximation of a richer model in the neighborhood of the equilibrium. However, risk aversion affects the outcome of a bargain, potentially in nonlinear ways that asymmetric bargaining power does not replicate well. Rudanko (2009) considers a model of wage posting with risk averse workers, and finds that in equilibrium, firms post contracts where wages are constant until either the worker's or firm's outside option forces a renegotiation of the wage. These wage contracts are time consistent inasmuch as firms and workers renegotiate when one has an incentive to separate under the existing wage contract, but not in the sense that the wage would be unchanged if it were renegotiated at any moment.

One interpretation of risk aversion in the model is that it represents a measure of the ability of workers to save and borrow to smooth consumption. If we assume an environment where risk averse workers cannot save or borrow, then workers will exhibit risk aversion in their bargaining behavior. If we assume that risk averse workers can buy and sell on a complete market of assets, then they will bargain as if they are risk neutral, seeking to maximize lifetime discounted income. If workers have access

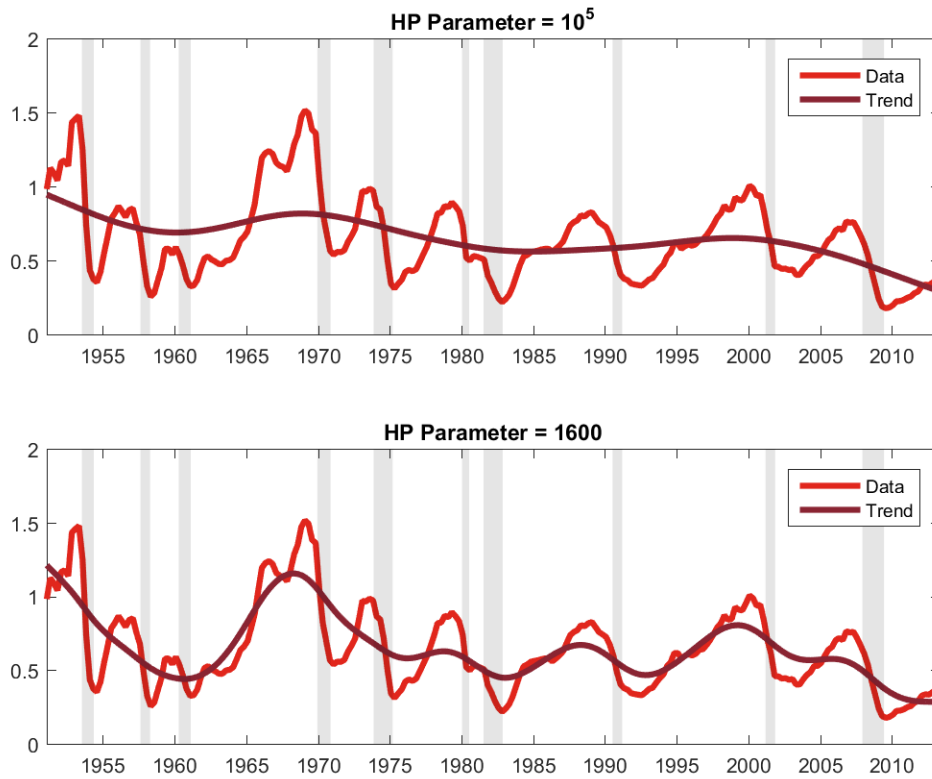


Figure 3.1: Labor market tightness and low-frequency trend. Labor market tightness is relatively volatile, so the standard choice of HP parameter, 1600 does not sufficiently remove business cycle fluctuations. Instead, I use parameter 10^5 .

to saving and borrowing, they will exhibit reduced risk aversion. Simulation does not find major differences resulting from the inclusion of risk aversion in the models.

3.2 OBSERVATIONS OF THE US LABOR MARKET

This section looks at aggregate data for the US labor market. It begins with a look at data on unemployment, vacancies, and their comovement. This is to illustrate the high volatility of unemployment and vacancies. Next is a description of data on matching

between firms and workers. This section concludes with an investigation of potential exogenous drivers of volatility for the model.

The observations in this section review analysis carried out in Shimer (2005). Shimer studies data from 1951 to 2003. I update this analysis using data from January 1951 to June 2013. Where possible, Shimer's comparable observations are given in parentheses to show that the observed trends do not change when more recent data is added, with the exception of productivity. I find a decrease and reversal in the contemporaneous correlation between productivity and the ratio of vacancies to the unemployed. Together with the consistency of all other data series, I consider this as suggestive evidence that the Bureau of Labor Statistics' (BLS) productivity series may have changed its cyclical behavior in recent decades.

As my focus is on explaining volatility at business cycle frequencies, long-term trends are removed using the Hodrick-Prescott filter. Following Shimer, the value of the smoothness parameter is set to 10^5 . This value is higher than the more commonly used smoothness parameter for quarterly data of 1600, calibrated in Hodrick and Prescott (1997) for GNP. This is necessary because the observations in this paper are of much higher volatility than the time series for which the HP filter was originally calibrated. Figure 3.1 illustrates the result of applying the HP filter on the ratio of vacancies to unemployment with both the standard smoothness parameter and the higher value.

3.2.1 LABOR MARKET TIGHTNESS AND THE BEVERIDGE CURVE

To understand firm decisions on posting, I need data on productivity and vacancy posting. Unemployment data will also be important to give a scale reference to vacancy numbers. This analysis will consider the unemployed to be the population

of job seekers. Specifically, the data on unemployment come from the Current Population Survey by the BLS, seasonally adjusted. This is the BLS U-3 measure, which does not include marginally attached workers. See Appendix A for specific data series.

There are alternative measures of the pool of job seekers that could be considered. Blanchard et al. (1990) document that flows from nonparticipation into employment are roughly as large as flows from unemployment into employment. Cole and Rogerson (1999) show that expanding the pool of searchers to include some of the marginally attached helps the MP model generate the observed negative correlation between job creation and destruction.

Both of these papers suggest that nonparticipants are less likely to find jobs than those who report that they are actively searching. Flinn and Heckman (1983) further document that the unemployed have higher hazard rates into employment than nonparticipants. This paper will use U-3 as the measure of unemployment because it is a group of self-identified people who are willing to work and are actively searching, they are documented to be more likely than other groups to join the ranks of the employed, and they constitute a well-defined pool of job-searchers.

Figure 3.2 is a graph of the log of the number of unemployed in the US according to CPS, and the trend, which is the log unemployment with the business cycle fluctuations filtered out. Unemployment fluctuates significantly over the business cycle, as the log of detrended unemployment has a standard deviation of 0.20.

The Job Openings and Labor Turnover Survey (JOLTS) is, to the best of the author's knowledge, the first and only attempt to estimate the total number of posted job vacancies in the US. The data extends back to December, 2000. Although it only has data for less than two complete business cycles, including a recession that can be considered exceptional, it is the best resource for precise measurement of job vacancies.

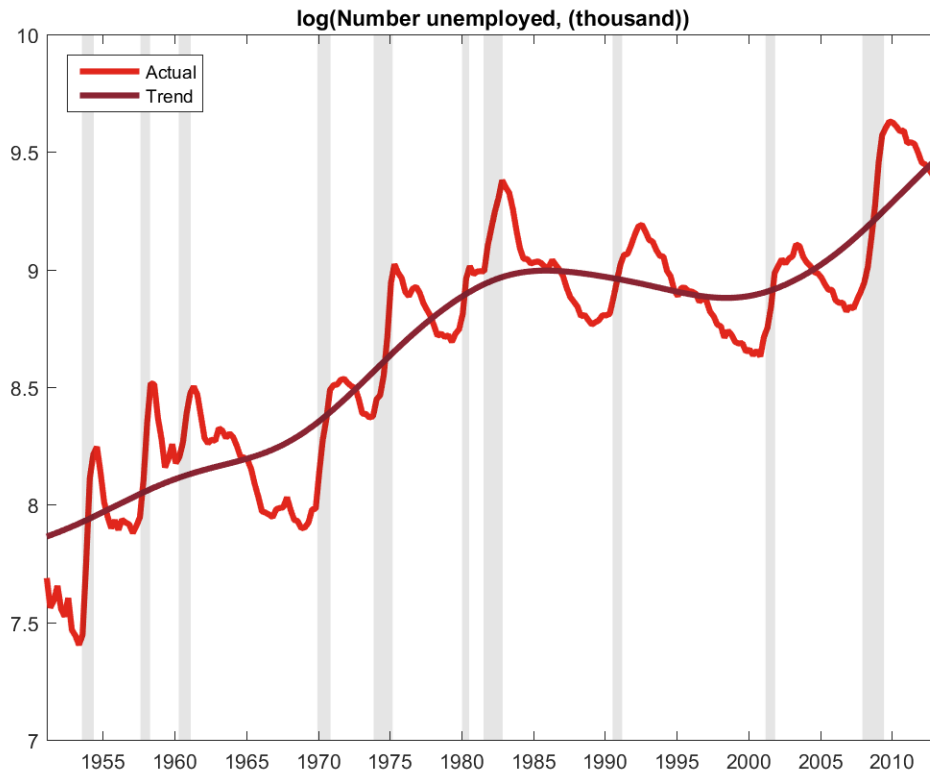


Figure 3.2: Log unemployment and low-frequency trend. Gray bars indicate recessions. Data are a quarterly average of U3 data from the BLS. Unemployment has a quarterly serial correlation coefficient of 0.94 (0.94), and the log of the detrended series has a standard deviation of 0.20 (0.19).

A precursor to JOLTS is the Conference Board's Help Wanted Index, henceforth the CB Index. This was a measure of the number of advertisements of vacancy postings in 45-52 major newspapers from large metropolitan areas in the US. The index is seasonally adjusted and normalized to a baseline of 100 in 1984. It is not a direct count of vacancies. However, Abraham (1987) found that the index does a good job of matching fluctuations in contemporaneous regional job vacancy counts.

Although the index is subject to long term fluctuations due to changes in the newspaper industry, filtering out long term trends should generate a good measure of business cycle fluctuations, which is what this paper seeks to explain. This follows the approach taken by Shimer (2005). Due to the decline of help wanted ads in newspapers, the Conference Board began an index of online job postings in 2005, and discontinued the print help-wanted index in 2010. Barnichon (2010) created a single index of Conference Board vacancy data, using a model of technology adoption to scale the two indexes and combine them.

The vacancy series for this study is comprised of JOLTS data for quarters when JOLTS was active; and Barnichon’s Conference Board data, rescaled to match JOLTS data, for quarters before JOLTS began. This process is described in more detail in Appendix C. The number of vacancies is then rescaled to correct for underreporting of vacancies, as estimated in Davis et al. (2006).

Figure 3.3 is a graph of the constructed vacancy series and its HP-filtered low-frequency trend. Vacancies are quite volatile, as the log of detrended vacancies has standard deviation of 0.20. This is the same magnitude as fluctuations in unemployment.

Figure 3.4 is a scatter plot of the unemployment rate and the vacancy rate, along with their average values over a rolling window of 20 years. This is the Beveridge curve. This graph exhibits two distinct features. The first is that the center of the Beveridge curve drifts over time. Elsbey et al. (2014) summarize recent research into the causes and effects of this long-term drift in the Beveridge curve. This paper does not attempt to study this question, focusing on business-cycle behavior of the labor market. The second feature of Figure 3.4 is that there is negative comovement of unemployment and vacancies, as observations cluster in several downward-sloping

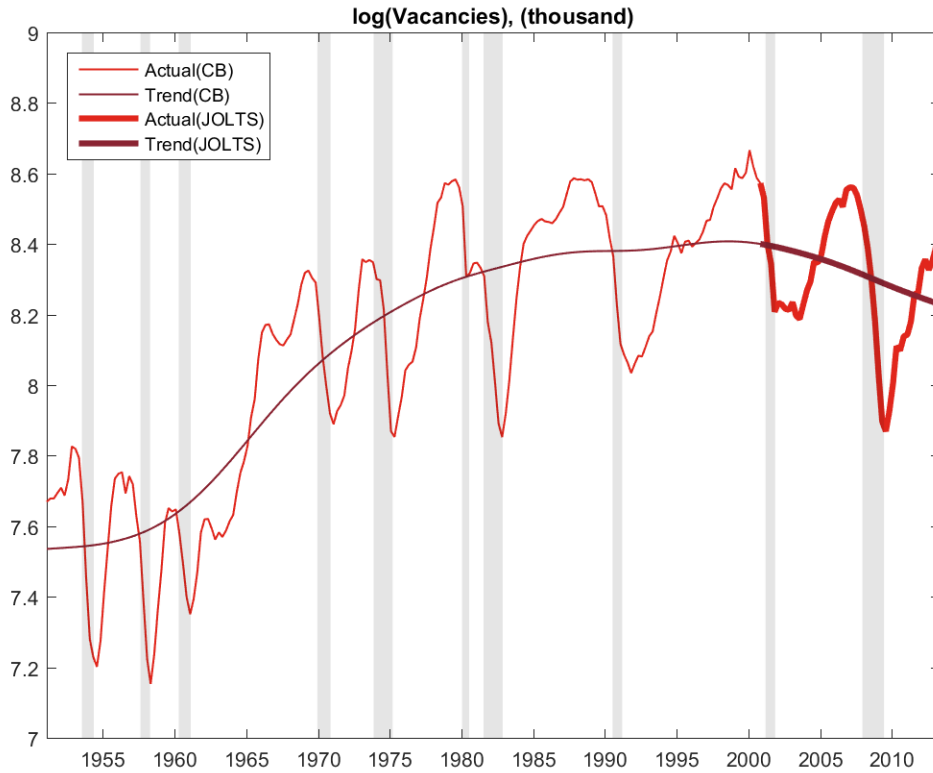


Figure 3.3: Log vacancies and low-frequency trend. Data is a quarterly average of JOLTS data from the BLS, and Conference Board vacancy data rescaled to match JOLTS. Vacancies have a quarterly serial correlation coefficient of 0.95 (0.94), and the log of the detrended series has a standard deviation of 0.19 (0.20).

curves. It is this feature of the Beveridge curve that will be sought in the simulations of the models in Section 3.6.

Figure 3.5 is a graph of fluctuations of detrended unemployment and vacancies. The strong negative correlation shows that unemployment and vacancies move contemporaneously and in opposite directions, suggesting that a common factor is driving fluctuations in both series.

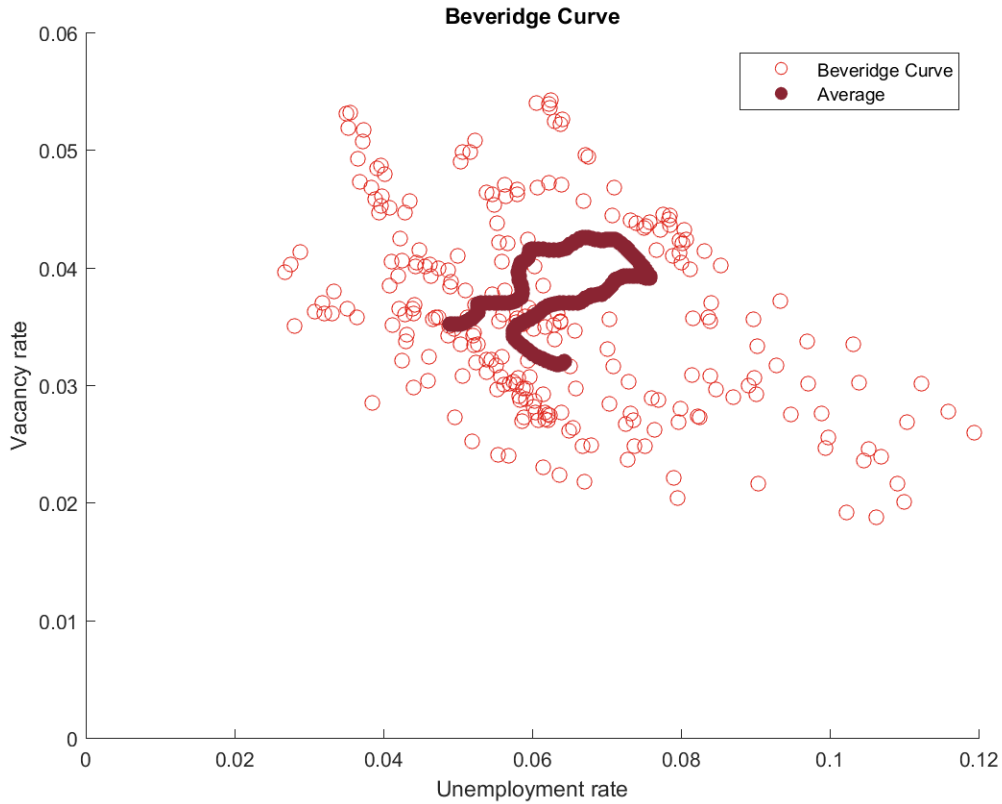


Figure 3.4: Beveridge curve. Empty circles indicate quarterly observations of the unemployment rate and vacancy rate. Filled circles indicate average unemployment rate and vacancy rate over 20-year windows.

It is now possible to construct a single measure of labor market tightness, which is the ratio of vacancies to unemployment, for 1951-2014. Denote tightness by θ .

I start by considering the JOLTS data on vacancies and CPS data on unemployment for 2001-2014. Averaged across all months, $\bar{\theta} = 0.416$. Since these data extend only over 1.5 business cycles, a more appropriate measure is probably the average over

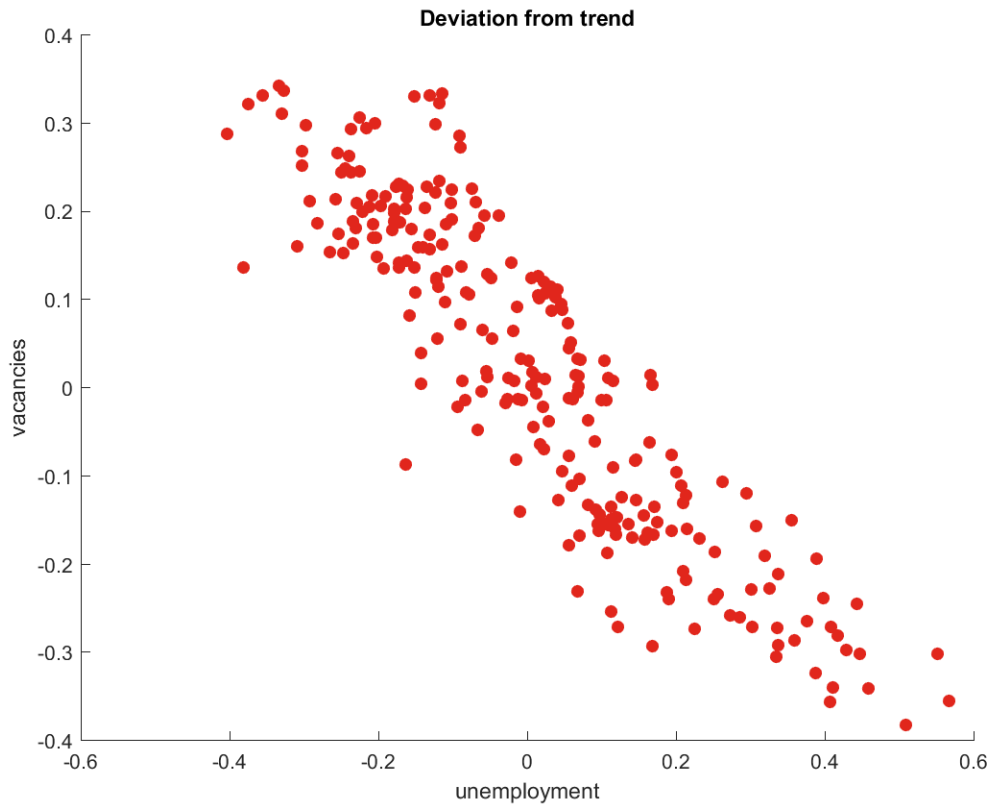


Figure 3.5: Business cycle behavior of Beveridge curve. Data are detrended unemployment and vacancies. The detrended series have a correlation coefficient of -0.90 (-0.90).

a single business cycle, as defined by NBER. Peak-to-peak, $\bar{\theta} = 0.516$ and trough-to-trough, $\bar{\theta} = 0.471$.¹

After combining the two vacancy series, the mean value of θ is 0.567. After correcting for issues of time aggregation in vacancy-posting and for vacancies that are targeted at the already-employed, I get an estimate of 0.6475 for $\bar{\theta}$.

¹3/2001 to 12/2007 and 11/2001 to 6/2009

Both unemployment and vacancies fluctuate to a great extent over business cycle frequencies, and with strong negative correlation. This means that their ratio has very large fluctuations relative to trend. The standard deviation of the log of detrended labor market tightness is 0.376. This is a measure of the length of the Beveridge Curve in the downward-sloping direction. This fluctuation is about ten times the prediction of standard calibrations of the Mortensen and Pissarides model.²

3.2.2 MATCHING BETWEEN FIRMS AND WORKERS

Having laid out the large and negatively correlated fluctuations in unemployment and vacancies, I turn to the mechanism by which they are related. The number of unemployed is, in equilibrium, determined by the hazard rate from unemployment to employment (the job-finding rate) and by the hazard rate from employment to unemployment (the separation rate). I first consider the job-finding rate, which I denote with f .

Given the large fluctuations in labor market tightness, one would expect job-finding rates to fluctuate as well. The BLS does not have direct observations of job-finding rates before 1976, and is subject to overestimating worker flows both into and out of employment as well as between jobs, due to errors measuring and recording reported job statuses and fields. However, it is possible to construct an estimate of the hiring rate. Following the procedure used in Shimer (2005), I estimate the job-finding rate as the ratio of the number unemployed for 5 weeks or more to the total number of unemployed in the previous month. I denote the job-finding rate with f . Note that this calculation implicitly assumes that the hazard out of unemployment

²"Standard calibration" refers to the calibration in Shimer (2005) where unemployment benefits are approximately 40% of wages.

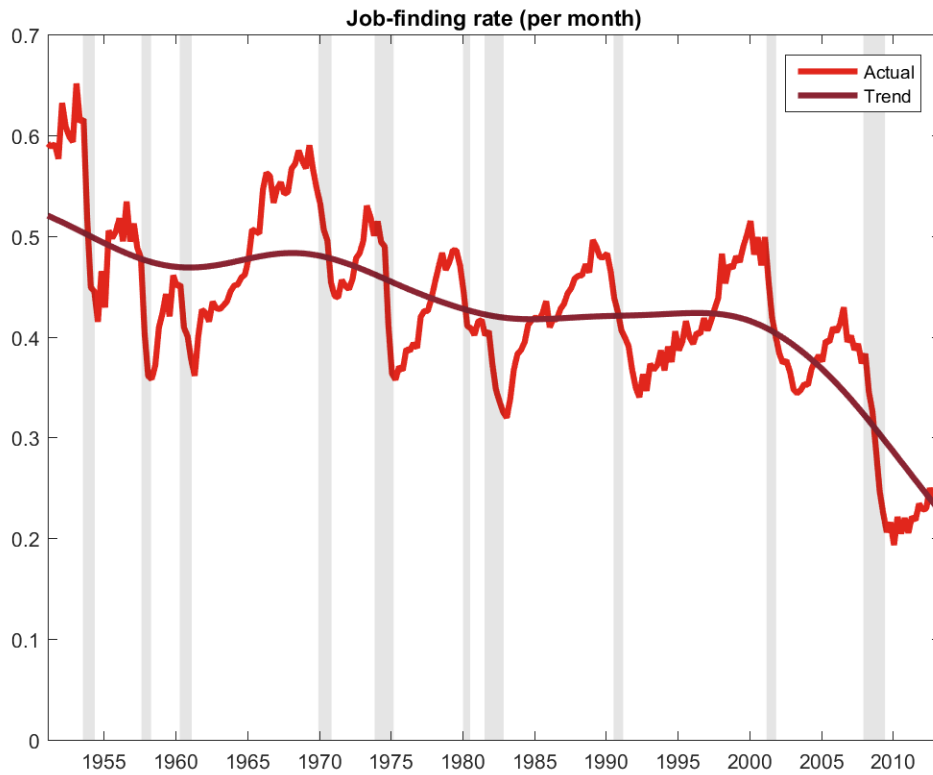


Figure 3.6: Job-finding rate and low-frequency trend. The data are quarterly averages of monthly data. The mean job-finding rate is 0.43 (0.45), and the log of the detrended series has a standard deviation of 0.13.

is not duration-dependent.

$$f_t = 1 - \frac{\text{unemployed}_{t+1} - \text{unemployed, short term}_{t+1}}{\text{unemployed}_t}$$

Figure 3.6 is a graph of f and the trend, the job-finding rate with the business cycle frequencies filtered out. It is clear that job-finding-rates vary substantially relative to trend.

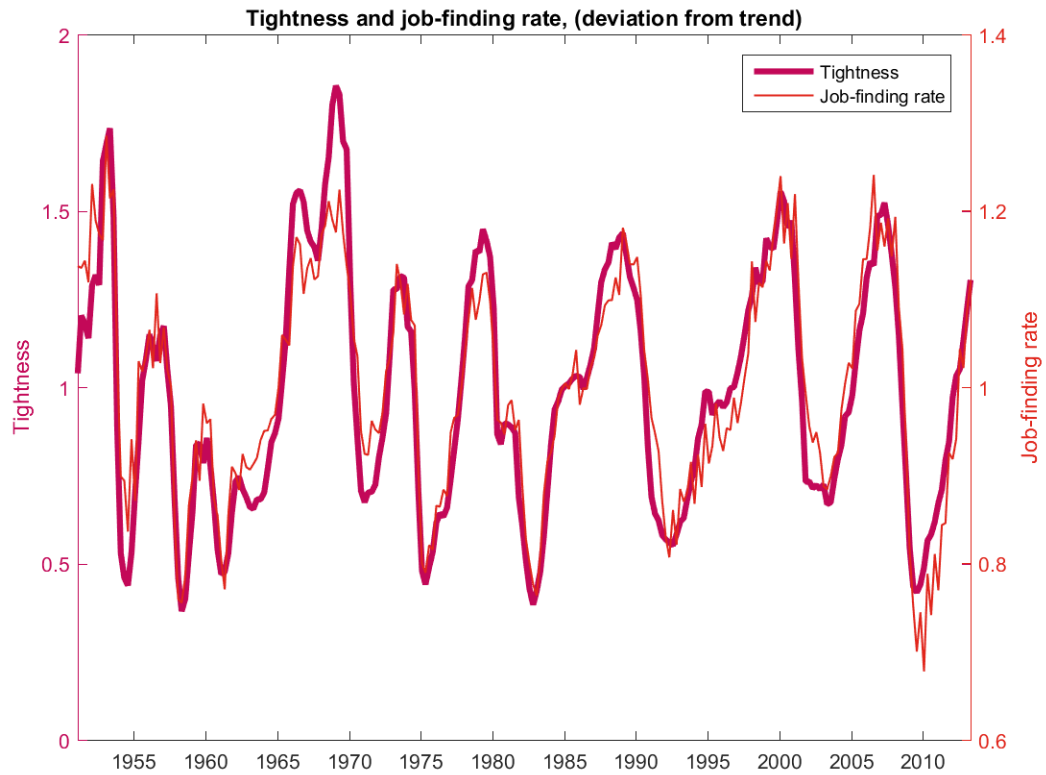


Figure 3.7: Job-finding rate and labor market tightness. Both series are relative to trend. The correlation coefficient is 0.93.

θ and f have a high correlation, as can be seen in Figure 3.7. This suggests that the job-finding rate can be well fitted with an appropriate increasing matching function of labor market tightness. When firms post many vacancies relative to the number of unemployed, workers exit unemployment more quickly, leaving a smaller number of unemployed. The job-finding rate thus provides a direct, negative relationship between vacancy posting and unemployment.

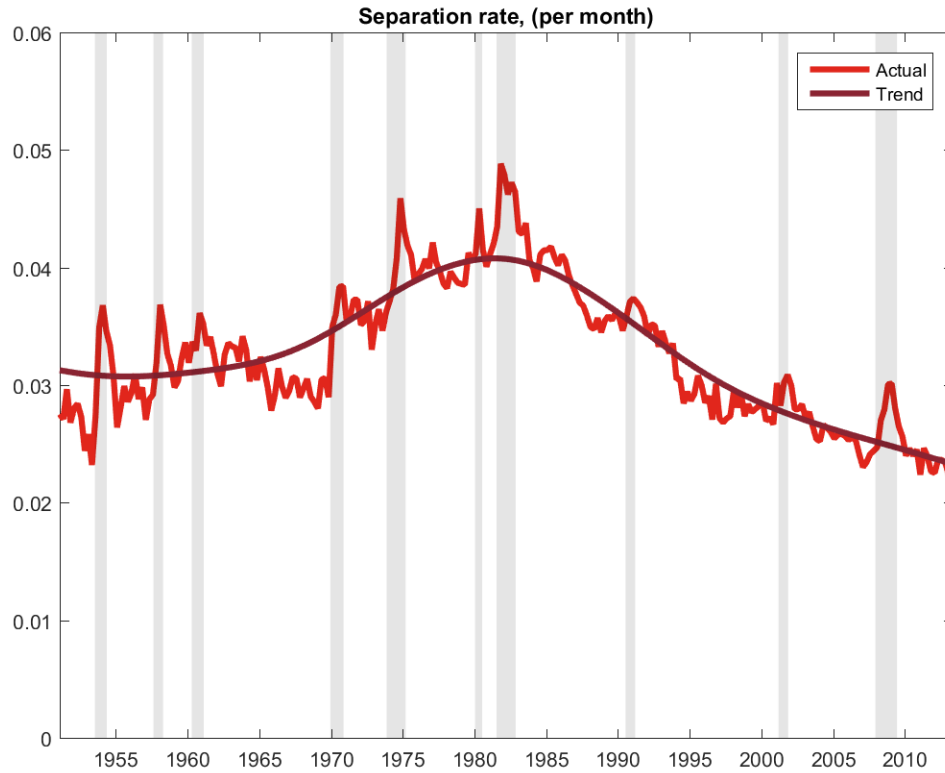


Figure 3.8: Separation rate and low-frequency trend. The data are quarterly averages of monthly data. The mean value is 0.032 (0.034), and the log of the detrended series has a standard deviation of 0.077 (0.080).

3.2.3 POTENTIAL DRIVERS OF FLUCTUATIONS

The natural complement to matching data is data on separations. Again, I will follow the procedure of Shimer (2005) to estimate separations s as a monthly hazard from employment into unemployment, using data on employment and short-term unemployment from the BLS. The natural assumption is that the hazard into unemployment is the number of newly unemployed divided by the previous period's number of employed. However, the data are collected monthly, so the estimate should correct

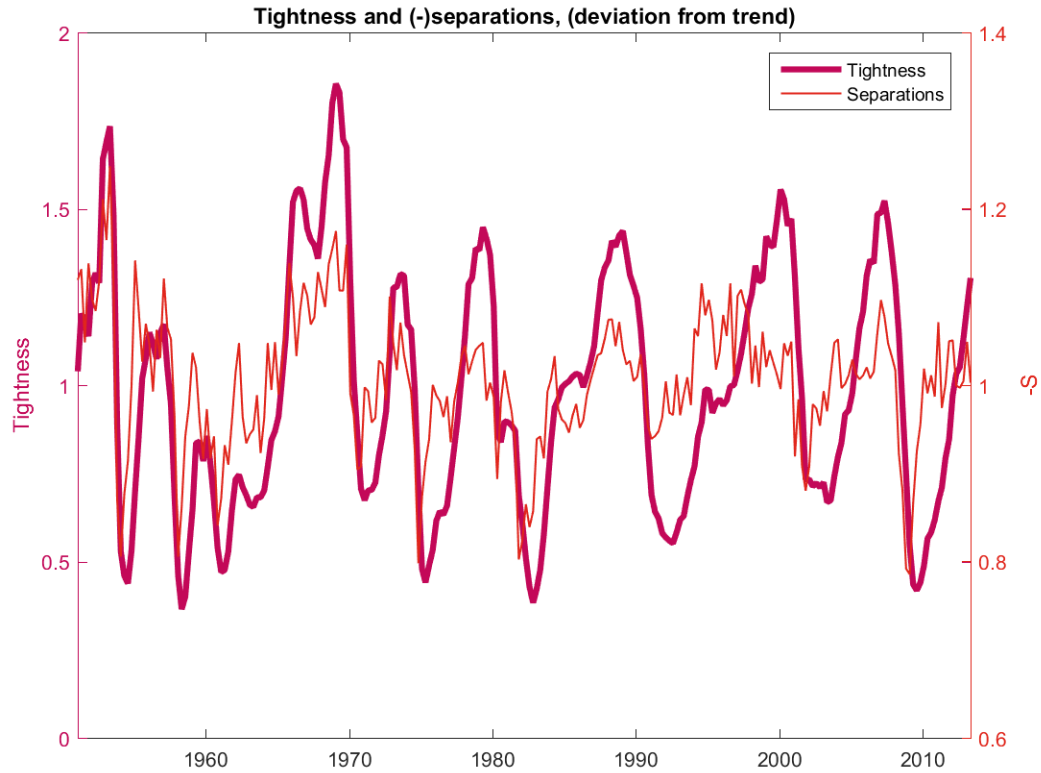


Figure 3.9: Separation rate and labor market tightness. Both series are relative to trend. The graph of the separation rate has been vertically inverted to more clearly show comovement. The contemporaneous correlation coefficient is -0.68 , and the correlation is maximized at -0.74 when separations lead tightness by one quarter.

for the number of workers who lost jobs and found a new job between survey dates.

$$s_t = \frac{\text{unemployed, short term}_{t+1}}{(1 - f_t)\text{employed}_t}$$

Figure 3.8 shows the separation rate and its trend. It fluctuates somewhat less than the job-finding rate, relative to trend. It has an average value of $\bar{s} = 0.0314$, implying that the average job has a duration of about 2 years and 8 months. Relative to trend, the separation rate varies less than the job-finding rate.

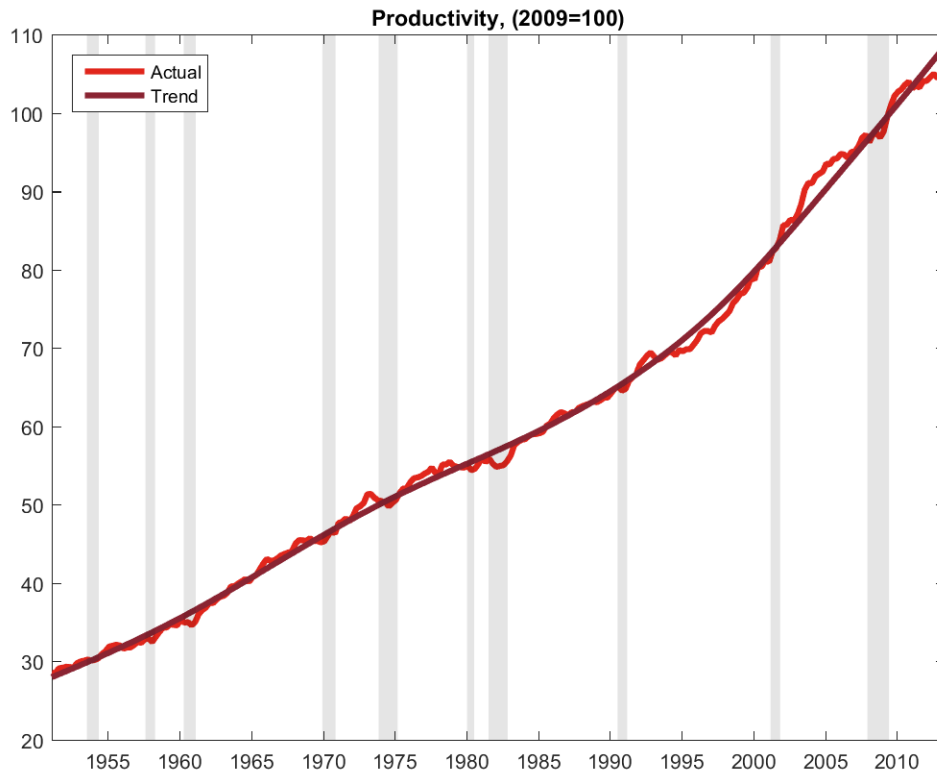


Figure 3.10: Aggregate productivity and low-frequency trend. The log of the detrended productivity series has a standard deviation of 0.0172. The volatility of detrended labor market tightness is 21.9 (20) times this.

One other potential driver of fluctuations in the labor market is labor productivity. Productivity affects the labor market by changing firms' incentives to post vacancies. If wages vary less than one-to-one with productivity, then when productivity is high, the value to firms of matching with workers is high. Consequently, more vacancies are posted, driving down unemployment. In this manner, productivity fluctuations can generate the movement along the Beveridge curve.

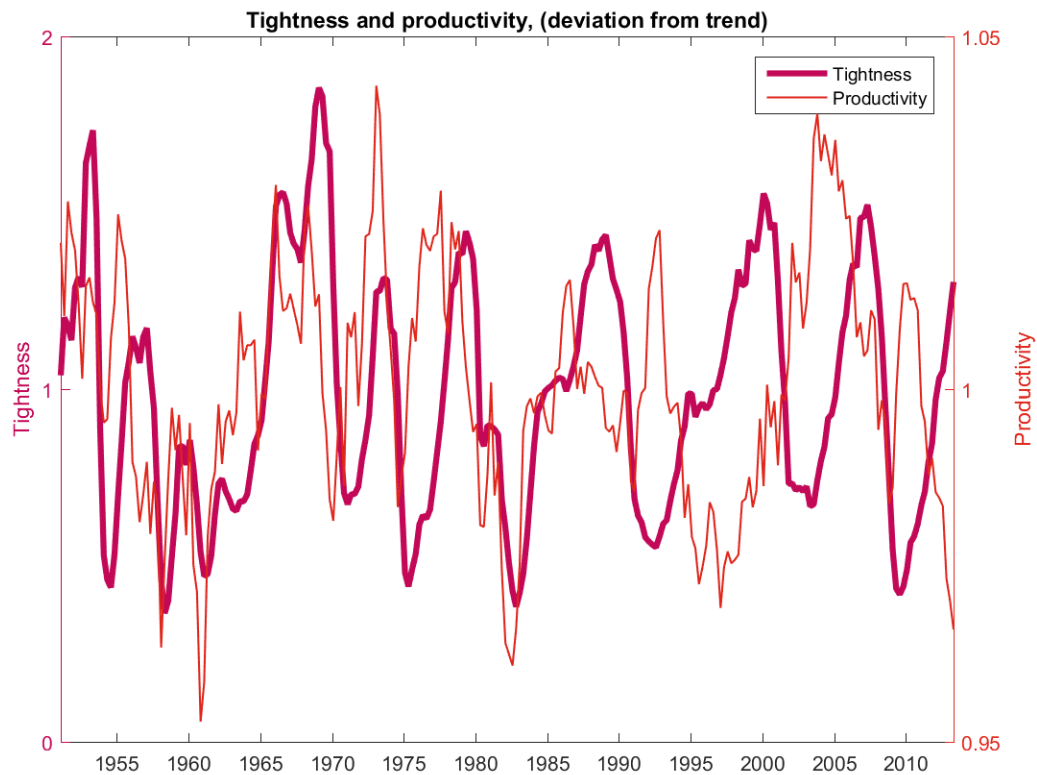


Figure 3.11: Productivity and labor market tightness. Both series are relative to trend. The contemporaneous correlation coefficient is 0.16, and the correlation is maximized at 0.28 when productivity leads tightness by three quarters.

The data for productivity comes from the BLS series on output per hour. It is observed every quarter and normalized to a reference year, in this case 2009. It is effectively output divided by hours, and should be considered an average value over the workforce at the time of measurement. Note that this is labor productivity, not TFP as is standard in macro papers. This because the relevant term for a firm’s hiring decision is the output of an additional worker. Figure 3.10 shows productivity and its HP filtered trend.

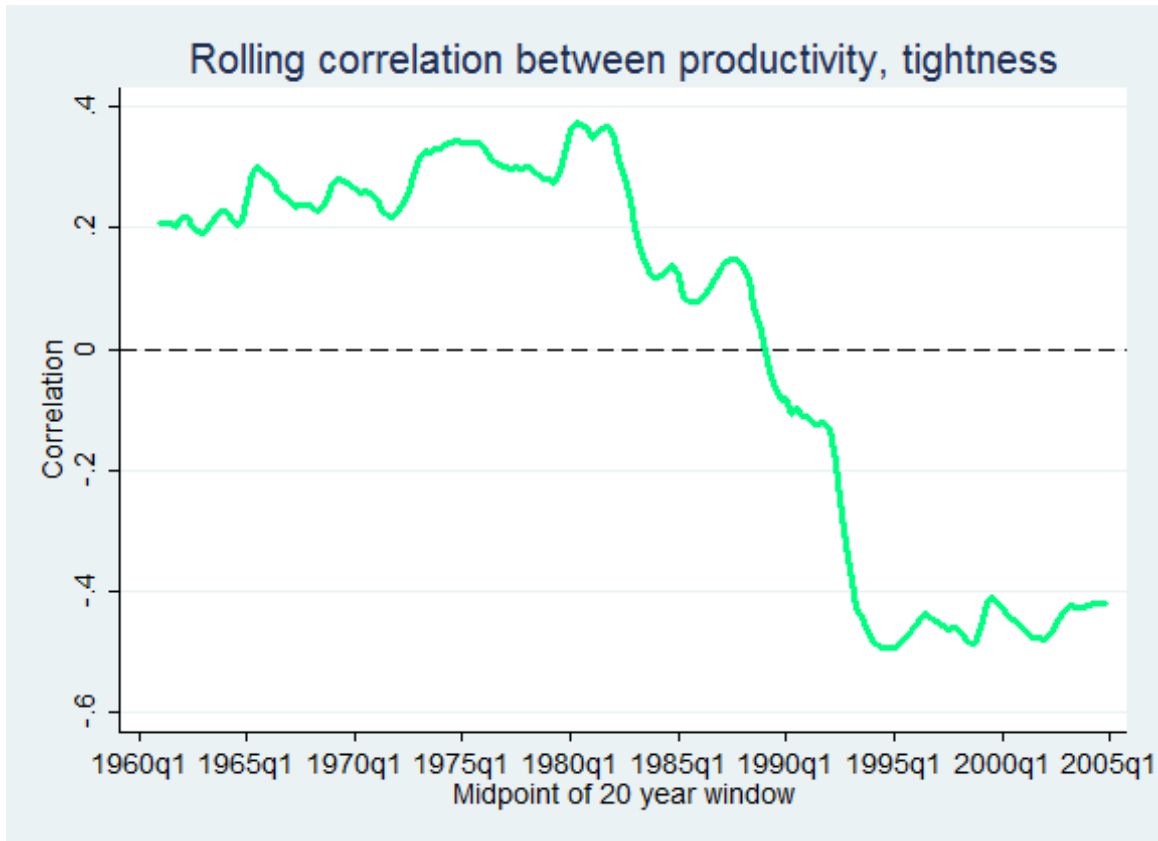


Figure 3.12: Contemporaneous correlation between productivity and tightness over 20-year rolling windows. Around the year 1990, there is a switch from a positive correlation to a negative correlation.

I assume that productivity drives fluctuations in vacancy posting by generating fluctuations in the profit from being matched with a worker. To show this, it would be useful to verify that wages fluctuate less than productivity. However, measures of aggregate wages are not readily available over the time frame considered in this paper, and those that exist are subject to concerns over which type of wage to use (hourly, monthly, full-time only, etc.).

Another concern is that the correlation between productivity and labor market tightness is low. This correlation is maximized when productivity is at a lag of 3 quarters, at a value of 0.28. Figure 3.12 graphs the contemporaneous correlation between labor market tightness and productivity within rolling 20-year windows. There is a high correlation between θ and p which decreases then turns negative between 1980 and 1995. This is a new observation since Shimer's analysis of the data, one which suggests that either the nature of the relationship between productivity and labor market tightness has changed, or that the measurement of either or both series is incorrect in later periods.

A possible explanation for this low correlation is that taking an average of hourly productivity may ignore compositional effects within the labor force. If hiring is more procyclical for low productivity workers than for high productivity workers, measured aggregate productivity could theoretically be countercyclical, even if the underlying average productivity per member of the labor force is procyclical. An increasing productivity gap between low skill and high skill labor over time is a potential explanation for the declining correlation between θ and p , although this is beyond the scope of this paper.

As a check against this, I repeated the above analysis of BLS' aggregate productivity measure using the TFP measure constructed by the San Francisco Fed according to the procedure of Basu et al. (2006). This is a TFP measure that is corrected for the skill composition of labor, as well as utilization of capital and labor. It correlates less well with labor market tightness than does labor force productivity over reasonable lags.³ For this reason, and to be consistent with the methods of Shimer and Hall and Milgrom, I use the BLS productivity series to calibrate the model.

³Up to 8 quarters

There is some dispute among explorations of the Shimer puzzle as to whether fluctuations in the separation rate should be considered as an exogenous driver of labor market volatility. Hall (2006) finds that cyclical variation in the separation rate has historically not been an important cause of fluctuations in unemployment, while job-finding rates have. Both Shimer (2005) and Hall and Milgrom (2008) study models where productivity fluctuations alone drive labor market fluctuations. One goal of this paper is to compare Nash bargaining over flow values to the bargaining methods in those models, so Section 3.6.2 considers a model where productivity shocks are the only exogenous fluctuations. However, the results in this paper will show that fluctuations in productivity alone generate excessive fluctuations in vacancies relative to unemployment fluctuations, and separation rate fluctuations are necessary to match the Beveridge curve.

Fujita and Ramey (2009) demonstrate, using data from 1976 to 2005, that the contemporaneous correlation between unemployment and the separation rate is much larger than that between unemployment and productivity. However, Shimer finds that fluctuations in the separation rate result in positive comovement between unemployment and vacancy posting, in contrast to the strong negative comovement observed in the data. Furthermore, separations and productivity are themselves highly correlated, so separation rate fluctuations adjust the slope of the simulated Beveridge curve but cannot on their own generate the right comovement of vacancies and unemployment.

3.3 MATCHING

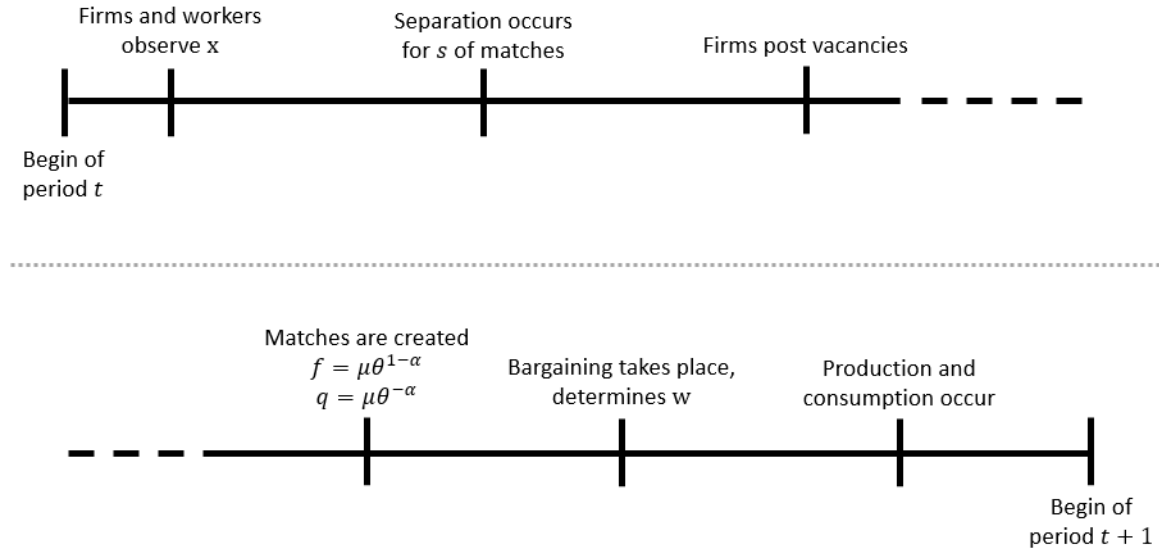


Figure 3.13: Timeline for the models in this paper

The models used in this paper are intended to be quite basic. There will be two exogenous state variables: labor productivity, defined as output per worker and denoted by $p \in P$, and the per period separation rate, denoted by $s \in S$. The state $x = (p, s)$ follows a Markov chain process. Every period, a new realization of x is drawn. Expectations of the next period's value of x' are informed by the current value of x . I assume rational expectations on the part of both households and firms.

The timing of the events in the model is as follows: at the beginning of the period, state $x = (p, s)$ is drawn and observed. Proportion s of existing matches dissolve. There is no endogenous separation. Firms post vacancies and new matches are created. Wages are determined by bargaining, then production takes place.

An equilibrium in this model has two components, determined by the realization of x : labor market tightness θ , and wage w . For the purposes of this section, take as given the wage schedule given state x . The next section will model the wage determination.

Matching takes place according to a CRS Cobb-Douglas function.

$$f(\theta) = \mu\theta^{1-\alpha} \quad (3.1)$$

$$q(\theta) = \mu\theta^{-\alpha} \quad (3.2)$$

f is the job-finding rate for workers and q is the vacancy-filling rate.

In the steady state, flows into and out of unemployment are equal. Condition (3.3) gives the resulting unemployment rate in equilibrium.

$$\text{unemployment rate} = \frac{s}{s + f} \quad (3.3)$$

I assume that firms are identical. They are risk neutral and have no market power. Production is CRS with labor, defined as the number of workers, as the only input. Without loss of generality, I assume that each firm consists of one job, either open or filled. There is a cost c per period of posting a vacancy. Firms enter and exit the market freely, so that in any period, firms will post vacancies up to the point where it is no longer profitable to post. The mass of workers is normalized to 1. Because matching (condition (3.1)) and production exhibit constant returns to scale, the ratio of vacancies to unemployment is sufficient to pin down the equilibrium. Vacancies and unemployment can then be backed out using the labor market steady state conditions.

I assume that workers are identical. They share the same period utility function $u(w)$ and lack access to a savings or storage technology. z is the dollar-equivalent of the utility from unemployment benefits or other support, along with any utility from leisure/disutility from being unemployed.

3.3.1 VALUE FUNCTIONS

There is a per-period discount rate r that is common to all households and firms. The state values to workers of being unemployed and employed, respectively, are given by

$$U(x) = u(z) + \frac{1}{1+r} E [fM(x') + (1-f)U(x')] \quad (3.4)$$

$$M(x) = u(w) + \frac{1}{1+r} E [(1-s)M(x') + sU(x')] \quad (3.5)$$

The state values to firms of vacant and filled jobs, respectively, are given by

$$V(x) = -c + qJ(x) \quad (3.6)$$

$$J(x) = p - w + \frac{1}{1+r} E [(1-s)J(x') + s * V(x')] \quad (3.7)$$

It is left implicit that w , f and q are functions of p , indirectly through θ for f and q .

Labor market tightness is determined by the zero profit condition

$$V(x) = -c + qJ(x) = 0$$

3.3.2 OFF-EQUILIBRIUM VALUE FUNCTIONS

Bargaining over state values requires considering deviating from the equilibrium wages in the current period. Under the assumption that precommitment to a wage schedule is not possible, in the subsequent period, the wage returns to equilibrium value. Denote the off-equilibrium wages as \tilde{w} . I define these off-equilibrium-wage value functions as

$$M(\tilde{w}, x) = u(\tilde{w}) + \frac{1}{1+r} E [(1-s)M(x') + sU(x')] \quad (3.8)$$

$$J(\tilde{w}, x) = p - \tilde{w} + \frac{1}{1+r} E [(1-s)J(x')] \quad (3.9)$$

3.4 BARGAINING

With the matching function and value functions defined, I turn to a description of the wage determination. Following the results in Chapter 1, the two Nash bargaining outcomes can be considered to be special cases of the alternating offers bargain between workers and consumers under limited commitment, where either the cost of delaying production is the relevant cost of bargaining, or where the risk of the match between the firm and the worker breaking down is. The other bargaining models considered, Kalai and Smorodinski and the method of Hall and Milgrom, are subsequently specified.

3.4.1 NASH BARGAINING

The Nash bargaining outcome was originally derived in Nash (1950) as a split of a surplus between two parties that satisfies the assumptions of scale invariance, Pareto optimality, symmetry, and independence of irrelevant alternatives. Binmore et al. (1986) explore the links between alternating offers bargaining and Nash bargaining, and make a distinction between two kinds of outside options, or threat points. In rejecting a proposed wage, firms/workers may both incur some cost from delay (the foregone profit and wage), and may increase the risk that the match breaks down. The cost of delay and the risk of destroyed surplus affect the agreed-upon wage in different ways.

In the case of bargaining over flow values, the surplus is the value, during an instant, of production relative to the outside option of delaying and bargaining. The worker's surplus with wage w is $u(w) - u(z)$, and the firm's surplus is $p - w + \gamma$.

Applying Nash's axiomatic bargaining solution over flow values solves the following problem:

$$\max_{\tilde{w} \in [0, p]} (p - \tilde{w} + \gamma)(u(\tilde{w}) - u(z))$$

The first order condition for the solution to this problem is the same as condition (3.10).

$$\frac{u(w) - u(z)}{p - w + \gamma} = u'(w) \quad (3.10)$$

On the other hand, if the primary cost of extending a wage bargain is the risk of breakdown, the bargain changes. The result is still equivalent to Nash's bargaining solution, but the surplus to be split in this case is the value over the duration of the match relative to the value if the match breaks down. I refer to this as the Nash bargain over state values. The worker's surplus is $M(x) - U(x)$ and the firm's is $J(x)$. The (asymmetric) Nash bargain over state values solves the following problem:

$$\max_{w \in [0, p]} (M(w, x) - U(x))^\beta (J(w, x))^{1-\beta}$$

The resulting wage solves condition (3.11).

$$\frac{\beta}{1 - \beta} \frac{M(x) - U(x)}{J(x)} = u'(w) \quad (3.11)$$

The standard assumption in models of job search and wage bargaining is Nash bargaining over state values. This can be understood as the result of a bargain over a wage contract, where the worker and the firm can each threaten to end the match.

3.4.2 KALAI SMORODINSKI BARGAINING

Like the Nash bargaining outcome, the bargaining solution of Kalai and Smorodinski (1975) is a unique split of a surplus defined by four axioms. KS bargaining replaces

the assumption of independence of irrelevant alternatives with the assumption of monotonicity. As with the Nash bargaining outcome, the surplus to be split can be the surplus over flow values or the surplus over state values. Unlike the Nash bargaining outcome, the KS bargaining outcome has not been derived from an alternating offers game.⁴

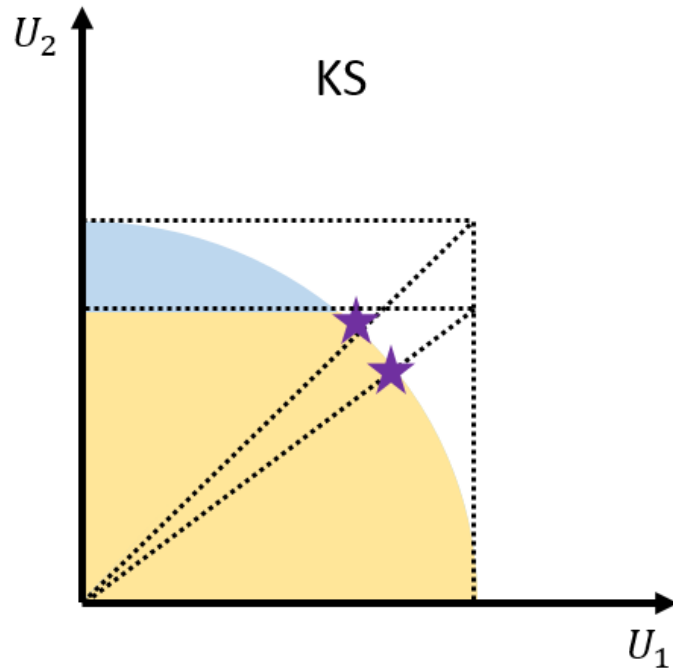


Figure 3.14: The Nash and KS bargaining outcomes

Under KS bargaining, the split of the surplus is proportional to the maximum value of the surplus that each party could obtain. Figure 3.14 offers an illustration of this solution. When the surplus is the union of the blue and yellow spaces, the solution to both bargaining problems is the higher star. When the surplus is the yellow space only, the higher star represents the outcome of Nash bargaining, which under independence from irrelevant alternatives is unaffected by the change in the surplus space. The lower star represents the outcome of KS bargaining. Bargainer 2's

⁴Moulin (1984) derives an auction game that implements the KS bargaining solution

maximum value of the surplus has declined with the removal of the blue portion of the surplus space, so their share of the equilibrium distribution of the surplus decreases accordingly.

First consider the KS bargain over flow values. The worker's surplus is $u(w) - u(z)$, and the firm's surplus is $p - w + \gamma$. The solution to the KS bargain is that the worker's and firm's surpluses are proportional to the maximum values that they could receive in the bargaining set, as in condition (3.12). Note that in the case of risk neutrality, condition (3.12) is equivalent to condition (3.10), resulting in the same wage outcome.

$$\frac{u(w) - u(z)}{p - w + \gamma} = \frac{u(p + \gamma) - u(z)}{p - z + \gamma} \quad (3.12)$$

The KS bargaining solution may also be applied to state values. To find the outcome of a KS bargain, I first need to find the maximum value that the surplus could be for workers or for firms, while leaving the other agent no worse off than they would be under their outside option. Define these maximum surpluses as $\bar{M}(x)$ and $\bar{J}(x)$. Define \underline{w} as the wage that would leave a worker no better off than under their outside option.

$$\begin{aligned} \bar{M}(x) &= u(p) + \frac{1}{1+r} E[(1-s)\bar{M}(x') + sU(x')] \\ \bar{J}(x) &= p - \underline{w} + \frac{1}{1+r} E[(1-s)\bar{J}(x')] \\ \underline{w} : M(\underline{w}, x) &= u(\underline{w}) + \frac{1}{1+r} E[(1-s)M(\underline{w}', x') + sU(x')] = U(x) \end{aligned}$$

The result of a KS bargain is that each parties realized share of the surplus is proportional to the maximum value of the surplus they would obtain while leaving the other party least as well off under their outside option. The condition for this outcome can be represented as:

$$\frac{M(x) - U(x)}{J(x)} = \frac{\bar{M}(x) - U(x)}{\bar{J}(x)} \quad (3.13)$$

The equilibrium wage is the value of w for which condition (3.13) holds.

3.4.3 HALL AND MILGROM (AO) BARGAINING

Hall and Milgrom (2008) calibrate a model where firms and workers negotiate wages under an alternating offers framework similar to the one in this paper, but with precommitment to a wage (or schedule of wages), and where counteroffers do not arrive instantaneously. Instead of $\Delta \rightarrow 0$, they assumed that counteroffers arrive each period, which is calibrated to one business day. They assumed a risk of the match breaking down during bargaining that was approximately four times their value of s , calibrating this value to match the volatility of unemployment.

Because the wages change every period in the model in this paper, I make a few modifications. Each period is treated as a month, with 20 subperiods. There are approximately 20 workdays in the average month, so this is equivalent to assuming that it takes one day to formulate a counteroffer.

In order to maintain comparability with the productivity process in the other bargaining models, productivity only changes every 20th subperiod. The excess probability of separation during delay is symmetric: $\delta_W = \delta_F = \delta \approx 3s$. At the end of the period, the productivity and separation shocks occur, and bargaining begins anew. The firm makes the first wage offer. Firms offer the lowest wage workers will accept. Workers would propose the highest wage firms would agree to, but this outcome never arises in equilibrium.

3.5 CALIBRATION AND ESTIMATION

Having laid out the models, the matter of calibrating the models for simulation remains. I choose to calibrate the model so that each period is one month, even though the productivity data is only available at quarterly intervals. With the high job-finding rate, which ranges between 0.2 and 0.65 per month, unemployment spells

average between 1.5 and 5 months. These spells of unemployment would not be well approximated by a model that only allows for unemployment spells of 0 months, 3 months, 6 months, etc.

The parameters to be calibrated can be placed in three categories. There are parameter values set by assumption to match standard values in the literature, parameters matched to the data in Section 3.2, and parameters calibrated within the estimated models. The parameters in the first two categories are the same across model specifications. Those in the third will differ between specifications. A summary of the calibrated parameter values may be found in Tables 3.4 and 3.5.

3.5.1 PARAMETERS SET BY ASSUMPTION

Each period is one month. Assuming an annual discount rate of 5%, we get a value of $r = 0.004$ per month.

In the model specifications with risk aversion, workers have constant relative risk aversion. The risk aversion parameter is set to $\phi = 1.5$. This is the value used by Kydland and Prescott (1982), and is at the high end of the range of parameters considered in Burdett and Coles (2003). Using a fairly high level of risk aversion makes the contrast between models with and without risk aversion more stark.

3.5.2 PARAMETERS CALIBRATED FROM LABOR MARKET DATA

The matching condition (3.1) has two parameters. The Cobb-Douglas matching parameter α is estimated by performing OLS over equation (3.14), using detrended data. This generates an estimate of how matching behaves over the business cycle. The resulting estimate is $\alpha = 0.6760$, outlined in Table 3.1.

Matching scale parameter μ is chosen to give the average job finding rate $\bar{f} = 0.4149$ when $\theta = 0.6475$. Generating the correct values of unemployment and vacancy

$$\log(f_t) = \log(\mu) + (1 - \alpha)\theta_t + \epsilon_t \quad (3.14)$$

Table 3.1: Estimation of matching parameters

Estimation of $\log(f_t) = \log(\mu) + (1 - \alpha)\theta_t + \epsilon_t$			
Sample: 1951Q2:2013Q2			
Variable	Value	Std Error	t-Stat
μ	1.0174	0.0038	4.5848
α	0.6890	0.0096	32.4823
R^2	0.7894		
SE	0.00791		
SSR	0.01582		
F-Stat(1,253)	948.19	Prob > F	0.0000

rates will only be possible if job-finding rates and separation rates fluctuate around their average values. The estimated value is $\mu = 0.5040$.

For Nash bargaining over state values with risk neutral workers, the worker bargaining power is set according to the Hosios condition, so that $\beta = \alpha$. Bargaining is symmetric under all other specifications.

Shimer (2005) calibrates models with shocks to productivity, and models with shocks to separation rates. In this paper, I model a 2-dimensional state space, where productivity shocks and separation rate shocks may be correlated. Define series y_t as the vectors of the detrended productivity and separation rates.

$$y_t \equiv \begin{pmatrix} \log\left(\frac{p_t}{p_t^{trend}}\right) \\ \log\left(\frac{s_t}{s_t^{trend}}\right) \end{pmatrix}$$

As both productivity and separations exhibit persistence and are correlated, I estimate the VAR in condition (3.15) to model their behavior.

$$y_t = Ay_{t-1} + \epsilon_t^y, \epsilon^y \sim \mathcal{N}(0, \Sigma) \quad (3.15)$$

The results of the estimation are given in Tables 3.2 and 3.3. In particular, note that, although the separation rate is more volatile in percent terms, productivity shocks are more persistent, and productivity has a strong negative effect on the next period's separation rate.

There are only quarterly observations of productivity, so manipulations must be made to develop a monthly AR(1) process with the same moments for every third observation as in condition (3.15).

$$y_t^{mo} = By_{t-1}^{mo} + \epsilon_t^{mo}, \epsilon^{mo} \sim \mathcal{N}(0, \Sigma^{mo}) \quad (3.16)$$

$$s.t. B^3 = A$$

$$B^2 \Sigma^{mo} B'^2 + B \Sigma^{mo} B' + \Sigma^{mo} = \Sigma$$

To construct a related time series with a diagonal variance-covariance matrix in the shocks, first eigen-decompose Σ^{mo} :

$$\Sigma^{mo} = Q\Lambda Q'$$

Premultiplying condition (3.16) by Q yields the following process, where $\tilde{y}_t = Qy_t^{mo}$, $\tilde{B} = QBQ'$, and $\tilde{\epsilon}_t = Q\epsilon_t$ with variance-covariance matrix Λ .

$$\tilde{y}_t = \tilde{B}\tilde{y}_{t-1} + \tilde{\epsilon}_t \quad (3.17)$$

I then follow the process suggested in Tauchen (1986) to approximate the process (3.17) by a Markov chain process over evenly distributed values of \tilde{y} . From this, the realizations of x_t of the shock process can be reconstructed. For instance, the i^{th} event

Table 3.2: Estimation of VAR(1) matrix A for productivity and the separation rate

p_t		s_t	
p_{t-1}	0.826*** (20.32)	p_{t-1}	-0.729** (2.84)
s_{t-1}	0.015 (-1.91)	s_{t-1}	0.614*** (12.34)
Observations		249	

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 3.3: Estimation of VAR(1) variance matrix Σ

	p	s
p	$5.74*10^{-5}$	$-8.6*10^{-5}$
s	$-8.6*10^{-5}$	$2.29*10^{-3}$

in the Markov process is given by the following method. \bar{s} is the average separations rate in the data, 0.0314.

$$x_i = \begin{pmatrix} \bar{s} * \exp(Q' \tilde{y}_i)_1 \\ \bar{p} * \exp(Q' \tilde{y}_i)_2 \end{pmatrix}$$

3.5.3 PARAMETERS CALIBRATED IN SIMULATION

The remaining parameters to calibrate are the cost of posting a vacancy c , the cost to the employer of delay during negotiation γ , and the flow value of unemployment z . These parameters will be calibrated in the steady state version of the model, where $p = \bar{p}$ and $s = \bar{s}$ in all periods. The target of this calibration is to match labor market tightness to its average value in the data.

Following Hagedorn and Manovskii (2008), I consider the total cost of posting a vacancy to consist of two costs: the administrative cost of search, and the cost of holding capital for the vacancy. As described in Silva and Toledo (2009), filling a

vacancy requires an average of 13.5 labor hours of administrative time, for a cost approximately equal to 4.5% of an average newly hired worker's wage. Correcting for the average duration of a posted vacancy, the administrative cost of a vacancy is given by condition (3.18).

$$c_{Admin} = 3q * (0.045w) \quad (3.18)$$

In addition to the administrative costs of searching and evaluating new hires, there is the cost of the capital required for the vacancy that goes idle until it is filled. Treating the cost of capital as one third of output and treating labor productivity as output net of capital costs, Hagedorn and Manovskii (2008) derive condition (3.19). I then take the total cost of posting a vacancy as the sum of the two terms, $c = c_{Admin} + c_k$, evaluated at the steady state wage and average values of the job filling rate, unemployment rate, and vacancy rate. I also take the cost of idle capital as the cost of delay, $\gamma \equiv c_k = 0.471$.

$$c_k = \frac{1}{3} * \frac{1 - \text{unemp rate}}{1 - \text{unemp rate} + \text{vac rate}} \left[1 - \frac{1}{3} \frac{1 - \text{unemp rate} + \text{vac rate}}{1 - \text{unemp rate}} \right] = 0.471 \quad (3.19)$$

The last remaining condition is one to determine the worker's flow value of unemployment, z . This parameter is chosen, along with the vacancy posting cost and the cost of delay, so that the steady state wage results in the targeted value of labor market tightness. The results depend on the bargaining model, but the cost of posting a vacancy is approximately $c \approx 0.56$, and the steady state wage is approximately 0.97. The calibrated flow value of leisure is given in Table 3.5.

The flow value of leisure is an influential parameter choice, and one for which there is not a clear consensus on the value or the appropriate way to measure. Hagedorn and Manovskii recalibrate the Mortensen and Pissarides model, choosing a value of z to match $var(\theta)$. They find a value of z that is approximately $0.955\bar{p}$. This implies

Table 3.4: Calibrated parameters

Parameter	Value	Calibration method
r	0.004	Annual discount rate of 5%
α	0.6760	Estimated by OLS
μ	0.5040	Calibrates to job-finding rate
β	0.6760	Hosios condition
ϕ	1.5	Kydland and Prescott (1982)
c	≈ 0.56	Target $\theta = 0.6475$ in steady state
γ	0.471	Estimated capital cost per job

Table 3.5: Calibrated values of leisure parameter z

Model	z
Nash state, risk neutral	0.154
Nash state, CRRA	0.672
Nash flow, risk neutral	0.469
Nash flow, CRRA	0.612
KS state, risk neutral	0.578
KS state, CRRA	0.671
KS flow, risk neutral	0.469
KS flow, CRRA	0.609
Alternating offers, risk neutral	0.479
Alternating offers, CRRA	0.641

that workers would be indifferent between working and not if wages fell approximately 4.5%, which is a strong assumption.

Hall and Milgrom choose a more moderate value of $z = 0.71$ in their model, based on research in Hall (2009). To do so, they calibrate a utility function to match results from previous research on risk aversion and intertemporal substitution of consumption, as well as wage elasticity of labor supply.

In this analysis, the flow value of leisure is calibrated within the model, based on the observable values of vacancy posting costs, capital costs, and labor market tightness. The resulting estimates are appreciably lower than the values proposed by Hagedorn and Manovskii or Hall and Milgrom, but generally higher than the value in Shimer (2005).

3.6 RESULTS

Using simulation of the results, I evaluate the various models on their fit. The primary metric by which the bargaining models will be assessed is their ability to match the business cycle behavior of the Beveridge curve, both in terms of the volatility of vacancies and unemployment and in terms of their negative comovement. I simulate the models with fluctuations in productivity and separation rates. This is followed by an analysis of simulations under productivity shocks only, as in prior literature. I conclude with a discussion of the cyclical behavior of wages, both as it relates to the model, and its relation to results in the literature.

3.6.1 MATCHING THE BEVERIDGE CURVE

There are two targets to consider when assessing which model best simulates the Beveridge curve. The first is the standard deviation of the log of labor market tightness, which has a value of 0.376 in the US data. This can be thought of as the length of the Beveridge curve from the Northwest portion of the graph to the Southeast. Figure 3.15 shows simulated Beveridge curves from the model specifications with risk neutral workers. Recall that vacancies, unemployment, and labor market tightness are detrended series in this analysis.

The other target is to match the slope of the Beveridge curve in the graph. This is measured by regressing the percent deviation of unemployment on percent deviation of vacancies. The results are given in Table 3.6.

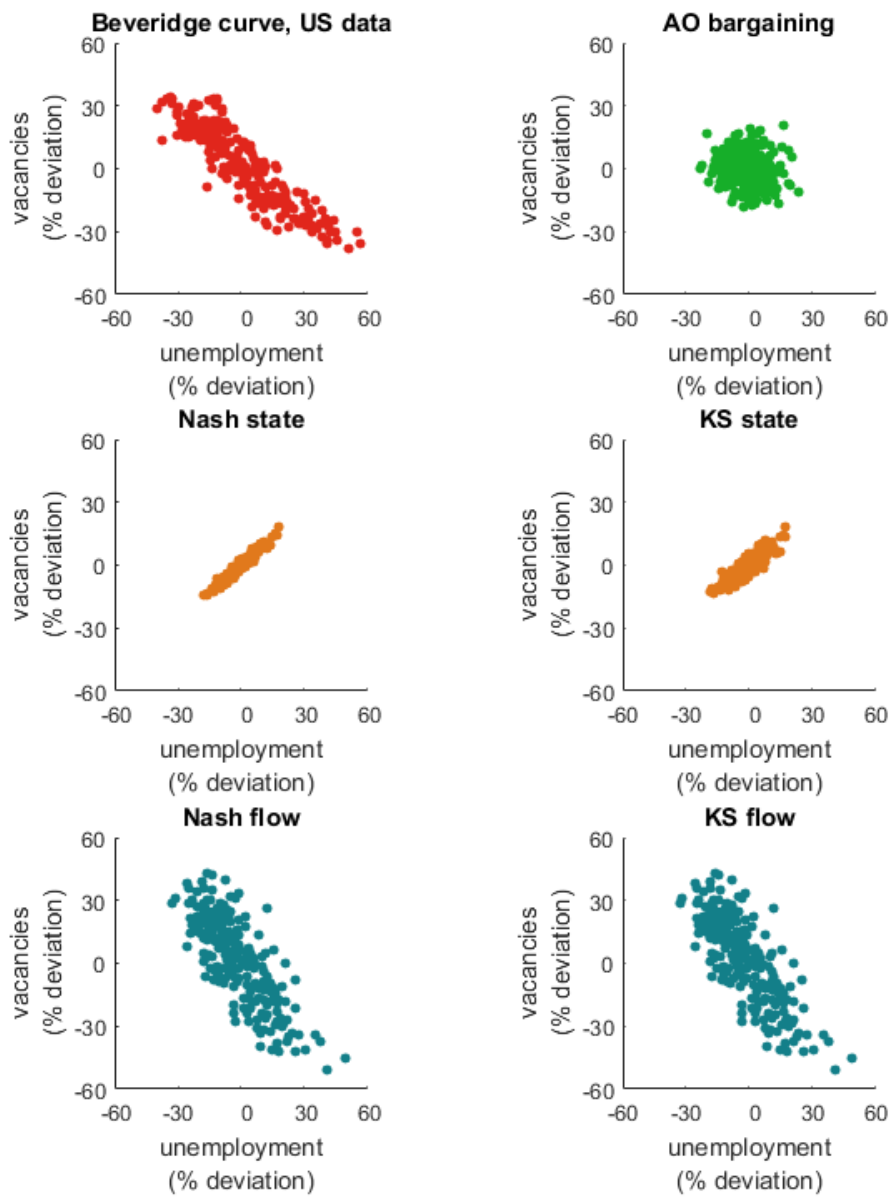


Figure 3.15: Beveridge curves from simulation with productivity and separation rate shocks. The presented results are for when workers are risk neutral.

Table 3.6: Simulated results, productivity and separation rate shocks

Model	$\sigma_{ln(\theta)}$	Slope
Nash state, risk neutral	0.018	0.82
Nash state, CRRA	0.064	0.40
Nash flow, risk neutral	0.364	-1.16
Nash flow, CRRA	0.474	-1.25
KS state, risk neutral	0.035	0.66
KS state, CRRA	0.040	0.64
KS flow, risk neutral	0.364	-1.16
KS flow, CRRA	0.470	-1.25
Alternating offers, risk neutral	0.132	-0.22
Alternating offers, CRRA	0.220	-0.74
US Data	0.376	-0.83

The models that most closely match the fluctuations of labor market tightness are Nash bargaining and KS bargaining over flow values with risk neutral workers. Recall that these models are equivalent. These models have excess fluctuation in vacancies and insufficient fluctuation in unemployment, but maintain the clear negative slope in the simulated outcomes. The models of bargaining over flow values with risk averse workers have excess variation in labor market tightness.

The model of alternating offers with risk averse workers better matches the slope, but with insufficient variation in labor market tightness, to the extent that there is not a visibly evident comovement between unemployment and vacancies. The models with bargaining over state values generate counterfactually upward-sloping Beveridge curves. The models with risk averse workers have more fluctuation in labor market tightness than their counterparts with risk neutral workers.

3.6.2 FLUCTUATIONS IN PRODUCTIVITY

A striking result from the simulations is the positive slope of the Beveridge curve under most specifications. This can be explained by a consideration of the effects of fluctuations in productivity alone. In this section, in keeping with the work of Shimer (2005), Hagedorn and Manovskii (2008), and Hall and Milgrom (2008), I calibrate and simulate the model with fluctuations in productivity as the exogenous random variable. The results are given in Figure 3.16 and Table 3.7.

In particular, note that the slope of the Beveridge curve is approximately -2.3 in every model. This is because conditions (3.1) and (3.3) specify a single curve in the (unemployment, vacancies) space when s , μ , and α are constant. Rearranging terms and implicitly differentiating, the slope of the Beveridge curve is given by condition (3.20), where $\bar{\theta}$ is the average value of labor market tightness.

$$\frac{d \text{ vacancies}}{d \text{ unemployment}} = -\frac{1}{\bar{\theta}} \frac{s + \alpha\mu\theta^{1-\alpha}}{(1-\alpha)\mu\theta^{-\alpha}} \quad (3.20)$$

When $\theta = \bar{\theta}$, condition (3.20) gives a value of $\frac{d \text{ vacancies}}{d \text{ unemployment}} = -2.3$. Only with bargaining over flow values are there sufficiently large fluctuations such that the curvature affects the average slope. Any fluctuations that affect the labor market exclusively through the firms' vacancy posting decisions result in a Beveridge curve that is steeper than in the data, one in which vacancies fluctuate too much relative to unemployment.

Adding fluctuations in the separation rate to the model adds movement along a positive slope. In particular, the negative correlation between productivity and the separation rate moves the slope towards zero. For the models of bargaining over flow values, the effect of productivity fluctuations is large relative to that of separation shocks, and the Beveridge curve generated retains a negative slope. For the models of

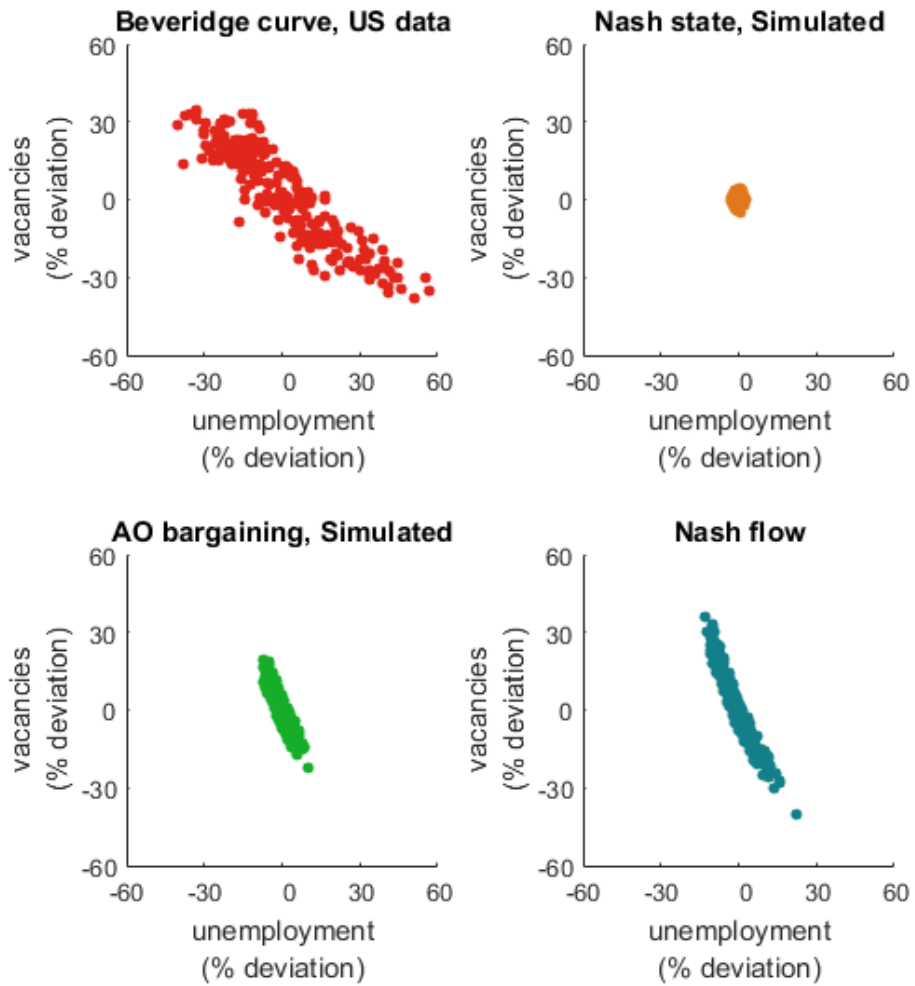


Figure 3.16: Beveridge curves from simulation with productivity shocks only. Again, the results are shown for risk neutral workers.

Table 3.7: Simulated results, productivity shocks only (risk neutral workers)

Model	$\sigma_{ln(\theta)}$	Slope
Nash state	0.020	-2.31
Nash flow	0.216	-2.22
KS state	0.040	-2.31
KS flow	0.216	-2.21
Alternating offers	0.115	-2.29
US Data	0.376	-0.83

bargaining over state values, the effect of the separation rate shocks predominates over the relatively small effect of the productivity shocks, leading to a positive comovement of unemployment and vacancies. For the alternating offers bargain, there is an overall negative comovement between unemployment and vacancies, but the effect of the separations is strong enough that it is difficult to discern in the graph.

3.6.3 INTUITION

The work of Hagedorn and Manovskii (2008) provides a useful framework for understanding what features of the equilibrium wage bargain are needed to achieve the large variance in labor market tightness. Hagedorn and Manovskii match the volatility of labor market tightness by making assumptions that generate an average wage close to the average productivity, and $\frac{dw}{dp}$ close to zero. In this way, the firm's flow profit from a match has large fluctuations relative to its average value. Table 3.8 shows how the bargaining models in this paper fit into that insight.

The first requirement for large fluctuations in vacancies and unemployment, a high wage, is achieved to the same extent in every specification, pinned down by the

Table 3.8: Effect of productivity shocks on the wage and value of a filled job opening

Model	Elasticity $_{w,p}$	Elasticity $_{J,p}$
Nash state, risk neutral	1.01	0.9
Nash state, CRRA	0.94	3.3
Nash flow, risk neutral	0.52	17.6
Nash flow, CRRA	0.37	23.2
KS state, risk neutral	0.99	1.7
KS state, CRRA	0.97	2.1
KS flow, risk neutral	0.52	17.6
KS flow, CRRA	0.38	23.0
Alternating offers, risk neutral	0.84	6.3
Alternating offers, CRRA	0.74	10.8

Table 3.9: Effect of separation rate shocks on the wage and value of a filled job opening

Model	Elasticity $_{w,s}$	Elasticity $_{J,s}$
Nash state, risk neutral	-0.02	-0.07
Nash state, CRRA	-0.02	-0.15
Nash flow, risk neutral	0	-0.77
Nash flow, CRRA	0	-0.77
KS state, risk neutral	-0.02	-0.11
KS state, CRRA	-0.02	-0.08
KS flow, risk neutral	0	-0.77
KS flow, CRRA	0	-0.77
Alternating offers, risk neutral	-0.01	-0.33
Alternating offers, CRRA	-0.01	-0.41

calibration of the model. The second requirement, that wages fluctuate very little relative to productivity, is best achieved under bargaining over flow values, followed by the alternating offers models, with bargaining over state values doing particularly poorly in this regard.

The near one-to-one movement of wages and productivity with bargaining over state values was explained by Shimer (2005). Because job-finding rates are high, a worker's outside option is near the value of being matched with another employer. This renders the surplus small, as the worker can effectively play their current match against future employers, capturing most of the change in productivity. The wage fluctuation is amplified by the higher job-finding rate when productivity is high, and the low rate when productivity is low. This effect is absent from bargaining over flow values, and is present in the alternating offers bargain to a lesser extent.

The second column of Table 3.8 shows the effect of changes of productivity on the value of being matched with a worker. There is a monotone inverse relationship between the effect of productivity on wages and the effect on the the firm's value of a filled job. As wages fluctuate less with productivity, firms' willingness to pay to match with workers increases.

Wages respond less to changes in productivity when workers are risk averse. This is consistent with prior results showing that the more risk averse party to a bargain gains a smaller share of the surplus, *ceteris paribus*. This result drives the higher fluctuations of labor market tightness when workers are risk averse.

A change in the separation rate can impact the firms' vacancy posting incentives in two ways. The first is that an increase in the separation rate shortens the duration of the match, reducing the value of being matched with a worker. This effect is unambiguous. The second effect is that a change in the separation rate may change the bargained wage, affecting the firms' profit. As Table 3.9 indicates, for the models

with bargaining over flow values, the separation rate has no effect on the wage. With bargaining over state values, the wage decreases when the separation rate increases, reducing the change in the value of a filled vacancy. With alternating offers, this also occurs, but the effect is smaller. The net result is that fluctuations in the separation rate have the largest effect on the firms' incentives to post vacancies with bargaining over flow values, and the smallest effect with bargaining over state values.

With bargaining over state values, the effect of productivity fluctuations is so small as to be overwhelmed by the effect of separation rate fluctuations, resulting in the positive slope in Figure 3.15. With bargaining over flow values, both productivity and separation rate fluctuations have large effects relative to other models, but the effects of productivity fluctuations are stronger, leading to the negative slope and large fluctuations in labor market tightness in the corresponding graph.

It is with the models of alternating offers where this insight is particularly important. Hall and Milgrom (2008) target the fluctuations in unemployment correlated with productivity fluctuations alone, leaving separation rate shocks and other shocks out of their simulations. However, adding separation rate fluctuations back into the model does little to generate the missing volatility in labor market tightness.

3.6.4 CYCLICAL BEHAVIOR OF WAGES

The simulation results also allow for comparison of the volatility of wages and unemployment across the business cycle. Solon et al. (1994) estimate the cyclicity of wages using the unemployment rate as the proxy for the business cycle, controlling for labor force composition effects by tracking workers with continuous spells of employment across multiple years. They find that wages are mildly procyclical, estimating $\frac{dn(w)}{d \text{ unemployment rate}} = -1.40^5$. This result is roughly in line with most

⁵For prime age men, the population with the least elastic labor supply.

Table 3.10: Matching wage fluctuations in Solon, Barsky, and Parker

Model	$\frac{d \ln(w)}{d \text{ unemployment rate}}$
Nash state, risk neutral	-1.49
Nash state, CRRA	-1.55
Nash flow, risk neutral	-0.51
Nash flow, CRRA	-0.30
KS state, risk neutral	-1.52
KS state, CRRA	-1.58
KS flow, risk neutral	-0.51
KS flow, CRRA	-0.31
Alternating offers, risk neutral	-1.28
Alternating offers, CRRA	-0.96
Solon et al	-1.40

other estimates produced using panel data, according to Abraham and Haltiwanger (1995). Table 3.10 shows how the bargaining models compare.

While bargaining over flow values does best at matching the Beveridge curve fluctuations, bargaining over state values does better at matching cyclical wage dynamics. With bargaining over flow values, the wage does not fluctuate sufficiently as the unemployment rate fluctuates. On the other hand, the models that do generate wage-unemployment comovement fail to replicate business cycle fluctuations along the Beveridge curve. As inflexible wages are important for generating fluctuations in vacancy posting, there is an inherent conflict between matching cyclical wage dynamics and matching cyclical movements in unemployment and vacancies. This is an area for further exploration.

3.7 CONCLUSION

This paper began by explaining a failure of current models of wage bargaining: they do not generate sufficient, negatively correlated comovement of unemployment and vacancies, relative to what is observed in US data. A new model of wage bargaining was suggested: the Nash bargain over flow values. This bargain is the result of an alternating offers bargain between firms and workers with rapid arrival of counteroffers, where rejecting a wage offer does not incur a risk of the match breaking down, and when credible commitment to a schedule of wages is not feasible.

The metric by which I judge the bargaining models is the ability to replicate the high variability of labor market tightness in the US. In order to replicate the downward-sloping Beveridge curve, productivity and the separation rate are used as the stochastic exogenous variables. Firms respond to changes in profit per worker by varying their hiring, and hence, vacancy posting rates. Wages that are near productivity in average and relatively unresponsive to changes in productivity are essential to ensure large procyclical variations in vacancy posting. These fluctuations in vacancy posting cause fluctuations in job-finding rates which lead to the variation in the unemployment rate, along with separation rate shocks.

Of the models considered, bargaining over flow values does best at matching the Beveridge curve, particularly with risk neutral workers. While the Nash bargain and Kalai and Smorodinski bargains generate similar results, given the more intuitive theoretical basis, I conclude that this model merits further study and application.

However, on the metric of cyclicity of wages, the Nash bargain over flow values does not do well at matching the data. The wage does not move enough with unemployment. However, this conflicts with the insight of Hagedorn and Manovskii that wages must be relatively acyclical to generate sufficient fluctuations in vacancy

posting. This suggests that a richer model may be necessary to match both wage and Beveridge curve dynamics. On-the-job search and/or endogenous separation may be useful extensions to this model.

The productivity measure is a basic average over all hours worked. The volatility may be biased towards zero by composition effects across the business cycle, and may even result in a spurious negative correlation between productivity and labor market tightness. A measure of average labor productivity that controls for composition effects could improve the correlation between productivity and tightness in the data.

There is not a consensus on how on-the-job search with wage bargaining should be modeled. The Nash bargain over flow values has potential for this area of research, based on its viability for generating the business cycle behavior of the Beveridge curve, but also because it can resolve issues of time inconsistency in the outside option when a worker decides between two employers.

APPENDICES A

APPENDIX TO CHAPTERS 1, 2, AND 3: DATA SOURCES

Data sources

Data series	Source
Unemployment	BLS series LNS13000000
Unemployment (< 5 weeks)	BLS series LNS13008396
Vacancies (Conference Board)	Conference Board vacancy postings, https://sites.google.com/site/regisbarnichon/research
Vacancies (JOLTS)	BLS series JTS00000000JOL
Employment	BLS series LNS12000000
Productivity	BLS series PRS84006093

The vacancy data is a combination of the JOLTS vacancy index and the Conference Board Help Wanted Index as compiled and adjusted in Barnichon (2010).

APPENDICES B

APPENDIX TO CHAPTER 1

B.1 PROOF OF SUBGAME PERFECT EQUILIBRIUM

Proof 2.1 This is a game with discounting as $\rho \in (0, 1)$ and with additively separable payoffs, so by Blackwell (1965), the one-shot deviation principle applies. A sufficient condition for subgame perfect equilibrium is to show that any single deviation from the strategy is not optimal.

Throughout, assume that workers and firms follow the strategy described in Strategy 1.1.

Claim 2.1.1 *Neither workers nor firms have an incentive to deviate from the equilibrium strategy in terms of proposed wages.*

Proof 2.1.1 Fix arbitrary productivity series $x = \{x_0, x_1, \dots\}$. Define $i = \operatorname{argmin}_{\{t\}} \text{s.t. } x_t) \neq x_0$ and $j = \operatorname{argmin}_{\{t>i\}} \text{s.t. } x_t \neq x_i$.

Assume that the worker and firm both follow the equilibrium strategy, and that in period 0, the worker proposes the wage. The worker proposes wage $\bar{w}(x_0)$ and the firm accepts. The wage does not change until period i . If $\underline{w}(x_i) > \bar{w}(x_0)$, the worker opens renegotiation, the firm proposes $\underline{w}(x_i)$, and the worker accepts. If $\bar{w}(x_i) < \bar{w}(x_0)$, the firm opens renegotiation, the worker proposes $\bar{w}(x_i)$, and the firm accepts. Define the path of wages under the equilibrium strategy as series $\{w^*\} = \{w_0^*, w_1^*, \dots\}$.

Suppose, by way of contradiction, the worker proposes $w \neq \bar{w}(x_0)$ in period 0, then follows the equilibrium strategy. Define the path of wages under this alternative

strategy as $\{\hat{w}\} = \{\hat{w}_0, \hat{w}_1, \dots\}$. In the next six paragraphs, I consider all cases in which either $i > 1$ or $i = 1$, and in which the worker's proposed wage w satisfies $w > \bar{w}(x_0)$, $w \in [\underline{w}(x_0), \bar{w}(x_0)]$, or $w < \underline{w}(x_0)$.

Consider first the case where $i > 1$ and the worker proposes $w > \bar{w}(x_0)$. The firm rejects the proposed wage, and the worker receives payoff $u(z) < u(w_0^*)$. In period 1, the firm proposes $\underline{w}(x_0)$, and the worker accepts. $\hat{w}_t \leq w_t^*, \forall t \in \{1, 2, \dots, i-1\}$, and $\hat{w}_t = w_t^*, \forall t \geq i$. The worker does not benefit from this deviation.

In the second case, $i > 1$ and the worker proposes $w \in [\underline{w}(x_0), \bar{w}(x_0)]$. The firm accepts the proposed wage, which remains unchanged until period i , at which point the wage is renegotiated. From period i on, the outcome is the same as if the worker had not deviated from the strategy. In the resulting wage series, $\hat{w}_t \leq w_t^*, \forall t \in \{0, 1, \dots, i-1\}$, and $\hat{w}_t = w_t^*, \forall t \geq i$. The worker does not benefit from this deviation.

In the third case, $i > 1$ and the worker proposes $w < \underline{w}(x_0)$. The firm accepts. In period 1, the worker opens renegotiation. The firm proposes $\underline{w}(x_0)$, and the worker accepts. The result is that $\hat{w}_t \leq w_t^*, \forall t \in \{0, 1, \dots, i-1\}$, and $\hat{w}_t = w_t^*, \forall t \geq i$. The worker does not benefit from this deviation.

In the fourth case, $i = 1$ and the worker proposes $w > \bar{w}(x_0)$. The firm rejects the proposed wage, and the worker receives payoff $u(z) < u(w_0^*)$. In period 1, the firm proposes $\underline{w}(x_1)$, and the worker accepts. Consequently $\hat{w}_t \leq w_t^*, \forall t \in \{1, 2, \dots, j-1\}$, and $\hat{w}_t = w_t^*, \forall t \geq j$. The worker does not benefit from this deviation.

In the fifth case, $i > 1$ and the worker proposes $w \in [\underline{w}(x_0), \bar{w}(x_0)]$. The firm accepts the proposed wage. In period 1 the wage is renegotiated and the outcome is the same as if the worker had not deviated from the strategy. In the resulting wage series, $\hat{w}_t \leq w_t^*, \forall t \in \{0, 1, \dots, j-1\}$, and $\hat{w}_t = w_t^*, \forall t \geq j$. The worker does not benefit from this deviation.

In the sixth case, $i = 1$ and the worker proposes $w < \underline{w}(x_0)$. The firm accepts, so that \hat{w}_0 . In the next period, the state x changes to x_1 . If $\hat{w}_0 \in [\underline{w}(x_1), \bar{w}(x_1)]$, the wage is unchanged, and remains unchanged until period j , when x changes. Under the equilibrium strategy, the wage in periods 1 to j would have been $w_1^* = \bar{w}(x_1)$. If instead $\hat{w}_0 < \underline{w}(x_1)$, the worker requests renegotiation in period 1, and the resulting wage of $\underline{w}(x_1)$ holds until period j . Under the equilibrium strategy, the wage in periods 1 to j would have been either $\bar{w}(x_1)$ or $\underline{w}(x_1)$. Lastly, if $\hat{w}_0 > \bar{w}(x_1)$, the firm requests renegotiation in period 1, and the resulting wage of $\bar{w}(x_1)$ holds until period j . Under the equilibrium strategy, the wage in periods 1 to j would have been $w_1^* = \bar{w}(x_1)$. In all variations of this case, $\hat{w}_t \leq w_t^*, \forall t \in \{0, 1, \dots, j - 1\}$, and $\hat{w}_t = w_t^*, \forall t \geq j$. The worker does not benefit from this deviation.

Therefore, there is no deviation from the wage proposal strategy that the worker may take, in any series of productivity draws $\{x\}$, that leaves the worker better off.

The proof for the firm's proposed wage is omitted, as is it is symmetric to the proof for the worker's proposed wages.

QED

Claim 2.1.2 *Neither workers nor firms have an incentive to deviate from the equilibrium strategy in terms of accepted wages.*

Proof 2.1.2 Suppose the state is x and the worker proposes the wage. By definition, firms are indifferent between accepting and rejecting wage offers $\bar{w}(x)$, so it is optimal to accept any lower wage offer. Workers are indifferent between accepting and rejecting wage offers $\underline{w}(x)$, so it is optimal to accept any higher wage offer.

QED

Claim 2.1.3 *Neither workers nor firms have an incentive to deviate from the equilibrium strategy in terms of opening renegotiation.*

Proof 2.1.3 Suppose the state is x and the wage in the previous period was w . If a firm were to open renegotiation, the worker would offer $\bar{w}(x)$, so if $w > \bar{w}(x)$, firms are better off if they request renegotiation. If a worker were to open renegotiation, the firm would offer $\underline{w}(x)$, so if $w < \underline{w}(x)$, workers are better off if they request renegotiation.

QED

QED

APPENDICES C

APPENDIX TO CHAPTER 3

C.1 NOTES ON JOLTS VACANCY DATA

Per Davis et al. (2013), 41.6% of all hires take place at firms that did not post a vacancy the previous month. They find that two-thirds of these hires can be explained by time-aggregation effects. JOLTS asks, on the last business day of the month, whether firms currently have a vacancy posted, but the number of hires is the total number from the previous month. If a vacancy is posted early in the month, and filled before the end of the month, there is a vacancy that does not get counted, and a hire that does get counted. The remaining gap is due to job-filling in the absence of a formal vacancy posting, or because a posting fails to meet the JOLTS definition of a vacancy in some other manner.

On the other hand, Blanchard et al. (1989) estimated that about 1/3 of all hires are job-to-job transitions. If I adopt the (admittedly strong) assumption that hiring of already-employed workers takes place in a separate labor market, I would need to reduce the measure of vacancies to obtain the relevant value of $\bar{\theta}$. Applying these corrections to the average value of θ in the data gives an estimated average labor market tightness of $\frac{2}{3} * \frac{1}{0.584} * 0.57 \approx 0.65$.

Vacancies are also defined somewhat restrictively in the JOLTS questionnaire¹. For example, JOLTS does not include job openings where work is intended to start

¹A brief description is available at the JOLTS website, <http://www.bls.gov/jlt/jltdef.htm>

more than 30 days in the future. Furthermore, JOLTS does not count openings for which firms are not actively recruiting, but the term “actively recruiting” is quite broadly defined, including firms that are accepting applications or making word-of-mouth announcements.

C.2 CONFERENCE BOARD DATA

In order to construct a long series of estimated numbers of vacancies, I rescale Bar-nichon’s combined help wanted index using OLS over the period of overlap.

$$\text{vac}_{JOLTS,t} = \beta_0 + \beta_1 \text{vac}_{CB,t} + \epsilon_t \quad (\text{C.1})$$

Table C.1: Estimation of vacancy series overlap

	(1)	(2)
	VJolts	VJolts
VCB	45.77*** (93.33)	44.10*** (13.79)
Constant		137.8 (0.53)
Observations	55	55
Adjusted R^2	0.781	0.778
Pseudo R^2		

t statistics in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Under the assumption that the value of zero would represent zero vacancies for both JOLTS and the CB index, I can restrict $\beta_0 = 0$. Table C.1 suggests that this is not too strong of an assumption. Estimation of (C.1) with a constant does not change the R^2 much, and the constant parameter has a p-value of 0.3.

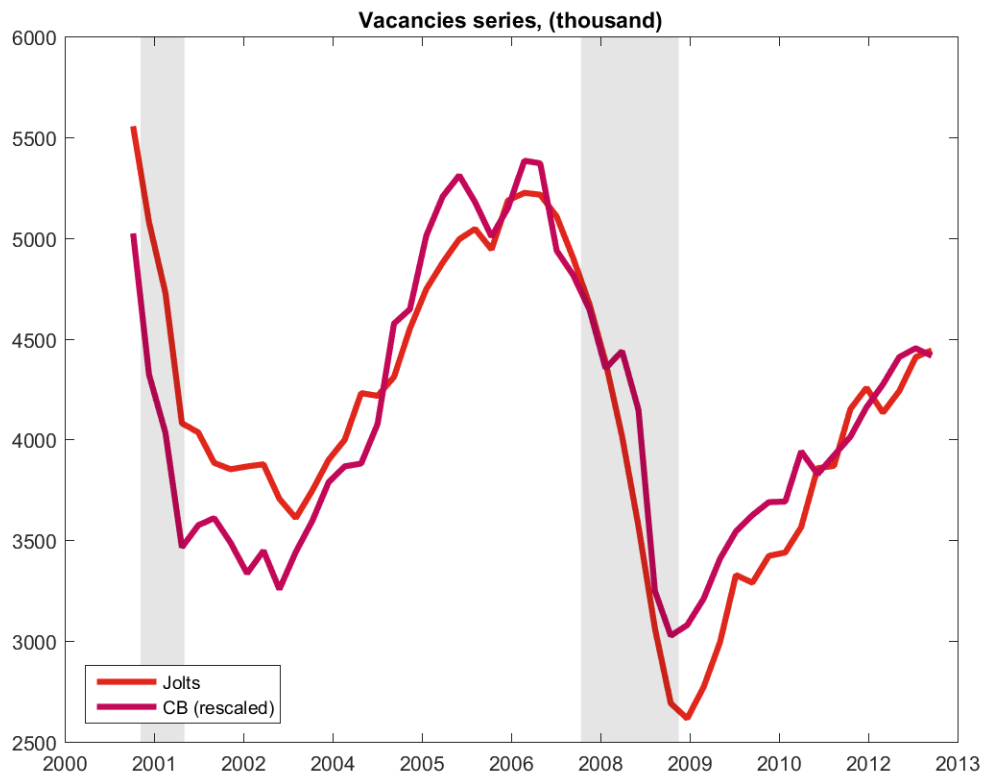


Figure C.1: Comparison of vacancy data series

Figure C.1 is a graph of the quarterly JOLTS data and the rescaled CB data. They match closely in terms of fluctuations over business cycle frequencies. In order to reduce the impact of the moderate difference in scale in the early periods, I use a gradual transition from the CB data to the JOLTS data. The constructed vacancy series is:

$$\text{vac}_t = \left\{ \begin{array}{ll} \text{vac}_{CB,t} & t < 2001Q1 \\ \frac{12-i}{12}\text{vac}_{CB,t} + \frac{i}{12}\text{vac}_{JOLTS,t} & t \in \{2001Q1, \dots, 2003Q4\}, \quad i = t - 2000Q4 \\ \text{vac}_{JOLTS,t} & t \geq 2003Q4 \end{array} \right\}$$

Elsby et al. (2014) do a similar splicing together of Barnichon's data and the JOLTS data. They use Barnichon's vacancy index for the entire time period 1951-2013, and rescale it so that the average labor market tightness is the same as the average labor market tightness found using JOLTS data from 2000-2013. Their method results in a slightly lower average labor market tightness from 1951-2000, but adopting their methods would not affect the business cycle frequency results on which this paper focuses.

BIBLIOGRAPHY

- ABRAHAM, K. G. (1987): "Help-wanted advertising, job vacancies, and unemployment," *Brookings Papers on Economic Activity*, 207–248.
- ABRAHAM, K. G. AND J. C. HALTIWANGER (1995): "Real wages and the business cycle," *Journal of Economic Literature*, 1215–1264.
- ALBRECHT, J. AND B. AXELL (1984): "An equilibrium model of search unemployment," *Journal of Political Economy*, 92.
- ANDREWS, D. W. K. (1993): "Tests for parameter instability and structural change with unknown change point," *Econometrica (1986-1998)*, 61, 821.
- BARNICHON, R. (2010): "Building a composite help-wanted index," *Economics Letters*, 109, 175–178.
- BASU, S., J. G. FERNALD, AND M. S. KIMBALL (2006): "Are technology improvements contractionary?" *The American Economic Review*, 96, 1418–1448.
- BINMORE, K., A. RUBINSTEIN, AND A. WOLINSKY (1986): "The Nash bargaining solution in economic modelling," *The RAND Journal of Economics*, 176–188.
- BLACKWELL, D. (1965): "Discounted dynamic programming," *The Annals of Mathematical Statistics*, 226–235.

- BLANCHARD, O. J., P. DIAMOND, R. E. HALL, AND K. MURPHY (1990): “The cyclical behavior of the gross flows of US workers,” *Brookings Papers on Economic Activity*, 85–155.
- BLANCHARD, O. J., P. DIAMOND, R. E. HALL, AND J. YELLEN (1989): “The Beveridge curve,” *Brookings papers on economic activity*, 1–76.
- BOROWCZYK-MARTINS, D., G. JOLIVET, AND F. POSTEL-VINAY (2013): “Accounting for endogeneity in matching function estimation,” *Review of Economic Dynamics*, 16, 440–451.
- BRÜGEMANN, B. AND G. MOSCARINI (2010): “Rent rigidity, asymmetric information, and volatility bounds in labor markets,” *Review of Economic Dynamics*, 13, 575–596.
- BURDETT, K. AND M. COLES (2003): “Equilibrium wage-tenure contracts,” *Econometrica*, 71, 1377–1404.
- BURDETT, K. AND D. MORTENSEN (1998): “Wage differentials, employer size, and unemployment,” *International Economic Review*, 39.
- COLE, H. L. AND R. ROGERSON (1999): “Can the Mortensen-Pissarides matching model match the business-cycle facts?” *International Economic Review*, 40, 933–959.
- COLES, M. G. AND A. MUTHOO (1998): “Strategic bargaining and competitive bidding in a dynamic market equilibrium,” *The Review of Economic Studies*, 65, 235–260.

DAVIS, S. J., R. J. FABERMAN, AND J. HALTIWANGER (2006): “The flow approach to labor markets: new data sources and micro-macro links,” *The Journal of Economic Perspectives*, 3–26.

DAVIS, S. J., R. J. FABERMAN, AND J. C. HALTIWANGER (2013): “The establishment-level behavior of vacancies and hiring.” *Quarterly Journal of Economics*, 128.

DIAMOND, P. (1982): “Wage determination and efficiency in search equilibrium,” *Review of Economic Studies*, 49.

ELSBY, M., R. MICHAELS, AND D. RATNER (2014): “The Beveridge curve: A survey,” *Journal of Economic Literature*.

FLINN, C. AND J. HECKMAN (1983): “Are unemployment and out of the labor force behaviorally distinct labor force states,” *Journal of Labor Economics*, 1.

FUJITA, S. AND G. RAMEY (2009): “The cyclical behavior of separation and job-finding rates,” *International Economic Review*, 50.

HAGEDORN, M. AND I. MANOVSKII (2008): “The cyclical behavior of equilibrium unemployment and vacancies revisited,” *American Economic Review*, 98.

HALL, R. AND P. MILGROM (2008): “The limited influence of unemployment on the wage bargain,” *American Economic Review*, 98.

HALL, R. E. (2006): “Job loss, job finding and unemployment in the US economy over the past 50 years,” 101–166.

——— (2009): “Reconciling cyclical movements in the marginal value of time and the marginal product of labor,” *Journal of political Economy*, 117, 281–323.

- HALL, R. E. AND A. B. KRUEGER (2012): “Evidence on the incidence of wage posting, wage bargaining, and on-the-job search,” *American Economic Journal: Macroeconomics*, 4, 56–67.
- HODRICK, R. J. AND E. C. PRESCOTT (1997): “Postwar US business cycles: an empirical investigation,” *Journal of Money, credit, and Banking*, 1–16.
- HOLDEN, S. (1994): “Wage bargaining and nominal rigidities,” *European Economic Review*, 1021–1039.
- HOSIOS, A. J. (1990): “On the efficiency of matching and related models of search and unemployment,” *The Review of Economic Studies*, 57, 279–298.
- KALAI, E. AND M. SMORODINSKI (1975): “Other solutions to Nash’s bargaining problem,” *Econometrica*, 43.
- KYDLAND, F. AND E. PRESCOTT (1982): “Time to build and aggregate fluctuations,” *Econometrica*, 50.
- MCCONNELL, M. M. AND G. PEREZ-QUIROS (2000): “Output fluctuations in the United States: What has changed since the early 1980’s?” *The American Economic Review*, 90, 1464–1476.
- MORTENSEN, D. AND C. PISSARIDES (1994): “Job creation and job destruction in the theory of unemployment,” *Review of Economic Studies*, 61.
- MORTENSEN, D. T. AND V. NAGYPAL (2007): “More on unemployment and vacancy fluctuations,” *Review of Economic Dynamics*, 10, 327–347.
- MOULIN, H. (1984): “Implementing the Kalai-Smorodinsky bargaining solution,” *Journal of Economic Theory*, 33, 32–45.

- NASH, J. (1950): “The bargaining problem,” *Econometrica*, 18.
- RUBINSTEIN, A. (1982): “Perfect equilibrium in a bargaining model,” *Econometrica*, 50.
- RUBINSTEIN, A. AND A. WOLINSKY (1985): “Equilibrium in a market with sequential bargaining,” *Econometrica: Journal of the Econometric Society*, 1133–1150.
- RUDANKO, L. (2009): “Labor market dynamics under long-term wage contracting,” *Journal of Monetary Economics*, 56, 170–183.
- SEDLÁČEK, P. (2016): “The aggregate matching function and job search from employment and out of the labor force,” *Review of Economic Dynamics*, 21, 16 – 28.
- SHI, S. (1995): “Money and prices: a model of search and bargaining,” *Journal of Economic Theory*, 67, 467–496.
- SHIMER, R. (2005): “The cyclical behavior of equilibrium unemployment and vacancies,” *American Economic Review*, 95.
- SILVA, J. I. AND M. TOLEDO (2009): “Labor turnover costs and the cyclical behavior of vacancies and unemployment,” *Macroeconomic Dynamics*, 13, 76–96.
- SOLON, G., R. BARSKY, AND J. A. PARKER (1994): “Measuring the cyclicity of real wages: How important is composition bias,” *The Quarterly Journal of Economics*, 1–25.
- STIROH, K. J. (2009): “Volatility accounting: A production perspective on increased economic stability,” *Journal of the European Economic Association*, 7, 671–696.

TAUCHEN, G. (1986): “Finite state markov-chain approximations to univariate and vector autoregressions,” *Economics Letters*, 20.

TREJOS, A. AND R. WRIGHT (1995): “Search, bargaining, money, and prices,” *Journal of political Economy*, 118–141.

VAN DEN BERG, G. AND G. RIDDER (1998): “An empirical equilibrium search model of the labor market,” *Econometrica*, 66.