A Quantitative Analysis of Unemployment Benefit Extensions

Makoto Nakajima*

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Abstract

Extensions of unemployment insurance (UI) benefits have been implemented in response to the Great Recession. This paper measures the effect of these extensions on the unemployment rate using a calibrated structural model featuring job search and consumption-saving decisions, skill depreciation, and UI eligibility. The ongoing UI benefit extensions are found to have raised the unemployment rate by 1.4 percentage points, which is about 30 percent of the observed increase since 2007. Moreover, the contribution of the UI benefit extensions to the elevated unemployment rate increased during 2009-2011; while the number of vacancies recovered, the successive extensions kept search intensity down.

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*Research Department, Federal Reserve Bank of Philadelphia. Ten Independence Mall, Philadelphia, PA 19106. E-mail: makoto.nakajima@phil.frb.org. Tel: +1-215-574-3905. An earlier version of this paper was circulated under the title "Unemployment Insurance and Unemployment Benefits." I thank Satyajit Chatterjee for his valuable comments as well as encouragement and Shigeru Fujita for stimulating discussions. I also thank Yongsung Chang, the anonymous referee, and seminar participants at the Macroeconomics Conference at Hitotsubashi University, the 2011 Midwest Macro Meeting, the 2011 Society of Economic Dynamics Annual Meeting, the 2011 Asian Meeting of the Econometric Society, and the 2012 ASSA Annual Meeting for helpful comments. The views expressed here are those of the author and do not necessarily reflect the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System. This paper is available free of charge at http://www.philadelphiafed.org/research-and-data/publications/working-papers/.

1. Introduction

Facing the most severe recession since the Great Depression, the U.S. government enacted a series of extensions of unemployment insurance (UI) benefits that provide an unemployed worker with a maximum of 99 weeks of UI benefits, compared with the regular duration of 26 weeks. While these extensions are one of the responses to the unemployment rate that reached 10 percent in October 2009, which was the second time this happened in postwar U.S. history (the other time was 1982-83), it is possible that the extensions themselves contributed to the rising unemployment rate through the incentive effect – encouraging jobless workers not to search for a job intensely and to remain unemployed so that they receive the UI benefits for an extended duration. This paper measures the effect of the ongoing UI benefit extensions on the unemployment rate using a calibrated structural model of job search.

Although there have been other attempts to measure the effect of UI benefit extensions on the unemployment rate, this paper is the only one that employs a structural model to answer the question. The structural approach has two advantages. First, the maximum duration of UI benefits for jobless workers was increased *gradually* with a series of extensions. Moreover, the extensions are *temporary*; many unemployed workers end up not receiving 99 weeks of benefits. A structural model can take into account this gradual and temporary nature of the extensions. Second, with a calibrated structural model at hand, counterfactual experiments can be implemented. For example, the model is used to evaluate how the extension in December 2010 affects the path of the unemployment rate.

The ongoing extensions of UI benefits are found to have contributed to an increase in the unemployment rate by 1.4 percentage points, which is 29 percent of the observed increase in the unemployment rate between 2005-2007 and 2009-2011 (4.8 percentage points). The remaining 3.4 percentage points are due to deteriorating economic conditions. In particular, 2.5 percentage points are due to the elevated separation rate, while the anemic hiring due to lower aggregate productivity contributes by 0.9 percentage point. Moreover, the contribution of the UI benefit extensions to the elevated unemployment rate accelerated from 2009 to 2011; while the number of vacancies has been recovering, the unemployment rate has remained elevated because of the successive UI benefit extensions. I also find that the December 2010 extension moderately slows down the recovery of the unemployment rate. The extension in December 2010 keeps the unemployment rate higher, by 0.6 percentage point on average during 2011.

There is a long list of empirical literature that quantifies the effect of changes of the level or duration of UI benefits on unemployment duration. These studies, many of which I discuss in Section 6.2, found that the duration of unemployment is longer (and thus the unemployment rate is higher) if the amount of UI benefits is higher or the duration of UI benefits is longer. Although these empirical results indicate a significant incentive effect of the current substantial UI benefit extensions on the unemployment rate, only a limited number of studies focus on the ongoing UI benefit extensions. Among the existing estimates, Barro (2010) (2.7 percentage points), Fujita (2010) (0.8-1.8 percentage points), and Aaronson et al. (2010) (0.5-1.25 percentage points) estimate a larger effect of the ongoing UI benefit extensions on the unemployment rate. On the other hand, Valletta and Kuang (2010) (0.4 percentage point) and Rothstein (2011) (0.1-0.5 percentage point) obtain a small estimate. All of these papers use reduced-form approaches, while I employ a structural model.

The model used in this paper is based on the model of Mortensen (1977) and Chetty (2008). While the model abstracts from the decision of accepting an offer, it is extended in the following ways: First, a stylized version of UI benefit extensions is introduced and the equilibrium transition path involving multiple policy changes and the time-varying separation rate and aggregate productivity is solved. Second, skill depreciation during unemployment spells is introduced. Third, eligibility for UI benefits is taken into account to capture the fact that less than half of the unemployed are receiving UI benefits in normal times. Fourth, as in Chetty (2008), workers are risk-averse and subject to a borrowing constraint. Finally, the number of vacancies is endogenized with the firm's decision to enter the labor market.

Recently, quantitative macroeconomic models with labor market frictions have been extensively developed to study various aspects of unemployment insurance. The current paper belongs to this group of the literature. Reichling (2007) studies the optimal UI policy in the steady state. Ljungqvist and Sargent (1998) emphasize the turbulence effect in explaining the U.S.-European difference in labor market dynamics. The turbulence effect is important in evaluating the effect of UI benefit extensions as well. Acemoglu and Shimer (2000) analyze the positive match quality effect of more generous UI benefits using a macroeconomic model. As workers become less desperate with more generous UI benefits, they can wait for better matches. Recently, Landais et al. (2011) and Mitman and Rabinovich (2011) investigate the optimal UI policy over the business cycles.

In what follows, Section 2 describes the ongoing extensions of UI benefits. Section 3 presents the model. Sections 4 and 5 address calibration and computation. Sections 6 and 7 present the main results. Section 8 concludes. The separate appendix includes a detailed description of the ongoing UI benefit extensions and computational methods, and the results of the sensitivity analysis.

2. Unemployment Benefit Extensions: Facts

Although standard UI benefits last 26 weeks in most states, the government often enacts extensions of UI benefits during economic downturns. There are two types of extensions, both of which were activated during the recent downturn. Remember that, under both types of extensions, the amount of benefits remains the same as that of the regular benefits. The first type of extension is called the extended benefits (EB) program. It is a permanent program that is automatically activated for a state whenever the unemployment rate of that state reaches a certain level. The EB program provides an additional 13 or 20 weeks of UI benefits if the unemployment rate exceeds 6.5 percent or 8.0 percent, respectively. During the recent recession, most states became eligible for the 20-week extension under the EB program. The second type of extension is not automatic; Congress enacts this type of extension temporarily in response to severe downturns. In response to the recent recession, Congress enacted the Emergency Unemployment Compensation program (EUC08) in June 2008. Combining the extensions under EUC08 (53 weeks) with the regular benefits (26 weeks) and the EB (20 weeks), an unemployed worker during the recent recession is entitled to UI benefits for up to 99 weeks in total.

Let me make three remarks about the nature of the ongoing extensions. First, they are generous compared with past extensions. Before the current extensions, the most generous ones in the past provided only about 60 weeks of UI benefits. Second, the EUC08 was gradually expanded. When the EUC08 was introduced in June 2008, only 13 weeks of additional UI benefits became available. It took a year and a half from the time the first EUC08 was enacted until the maximum of 53 weeks of additional UI benefits became available. In the main experiment of the paper, this gradual expansion of the ongoing extensions is captured by the model. Third, the extensions are temporary. Although the number 99 is widely cited to describe the generosity of the ongoing extensions, not all unemployed workers actually end up enjoying the full 99 weeks of extended UI benefits because of the temporary nature. The additional 73 weeks of UI benefits are grouped into five tiers, and an unemployed person can apply for a higher tier only by the specified expiration date. For example, if an unemployed person is still receiving the regular benefits at the expiration date, he cannot receive any of the extended benefits. This temporary nature is also captured by the model.

3. Model

After the environment is described, problems of the worker and the firm are characterized and the equilibrium is defined. Since the equilibrium is defined recursively, time script is omitted and a prime is used to denote the variables in the next period wherever appropriate.

3.1. Preferences

Time is discrete and infinite and starts from period 1. The model is inhibited by a mass of infinitely lived workers and firms. The total measure of workers is normalized to one. Workers maximize expected lifetime utility. Utility is additively time separable, with the time discount factor β. Period utility takes the form of $u(c, s)$ with the consumption of goods c and search intensity s. Firms are risk neutral and maximize their expected discounted sum of profits, with discount rate r.

3.2. Technology and Wage Determination

Only a matched pair of a worker and a firm can produce. Production is characterized by $y_t = z_t h$, where z_t is aggregate productivity, and $h \in \{h_1, h_2, ..., h_H\}$, where $h_1 < h_2 ... < h_H$ is the skill level of the worker. z_t is constant $\overline{z}$ in the steady state, while it is time-varying in the economy with transition dynamics. h changes stochastically with the transition probability $\pi^h_{u,h,h'}$. In particular, an employed worker accumulates skills with probability $\pi^h_{0,h_i,h_{i+1}}$, while an unemployed worker loses skills with probability $\pi^h_{1,h_i,h_{i-1}}$, as in Ljungqvist and Sargent (1998).

Output y_t is shared between the worker and the firm. The wage that the worker receives is assumed to be $w(z_t)h$. $w(z_t)$ is a function of aggregate productivity in order to capture the real wage stickiness. Generally, if the wage is modeled as the outcome of bargaining between the firm and the worker, the wage depends on all the individual characteristics of the firm and the worker, including the level of asset holdings of the worker. However, it was found that the bargaining outcome is not too sensitive to the level of asset holdings. For a more general bargaining setup, see Nakajima (2012). The profit of a firm matched with a type-h worker is $(z_t - w(z_t))h$.

3.3. Labor Market

A worker can be either employed ($u = 0$) or unemployed ($u > 0$). For an unemployed worker, u represents the length of the ongoing unemployment spell. An unemployed worker receives UI benefits if he is eligible and searches for a job. Workers with different productivity levels search in different markets.[1] Since individual productivity is characterized by h, and the worker's wage and the firm's profits also depend solely on h (and aggregate productivity z_t), it is natural to assume that there are separate markets for each h. Let s, S^h, and V^h denote the individual search effort, the aggregate search effort in market h, and the number of vacancies posted in market h, respectively. The number of new matches created in market h, M^h, can be expressed by the matching function $M^h = m(S^h, V^h)$. Assuming a constant returns to scale matching function, the matching probabilities per search effort, f^h, and per vacancy, d^h, are functions of labor market tightness, $\theta^h = V^h/S^h$. When an unemployed worker of type h searches with an intensity s, the job-finding rate is $f^h s$. Job separation is exogenous and characterized by separation rate λ_t, which is the same across all workers. It is constant $\overline{\lambda}$ in a steady-state equilibrium but can be time-varying in an equilibrium with transition. Firms can enter a market h by posting a vacancy at the flow cost of κ.

3.4. Financial Market

Workers can save and borrow to smooth consumption over time. Markets are incomplete: workers cannot trade state-contingent securities. Let k denote the asset holdings of a worker. The interest rate associated with the asset is constant at r. Workers are subject to a borrowing constraint $k \geq \underline{k}$.

3.5. Unemployment Insurance Program

The public UI program is characterized by $\{b, q, B(x, a)\}$. b is the amount of UI benefits. q is the amount of non-UI benefits that are available for unemployed workers who are either (i) ineligible for UI benefits or (ii) eligible but have exhausted UI benefits. $a = 1$ means the worker is eligible for UI benefits, while $a = 0$ means the worker is ineligible. $x = 0$ indicates that the worker is eligible only for the regular (Tier 0) UI benefits, and $x \in \{1, 2, .., X\}$ indicates that a worker is eligible for extended UI benefits up to Tier x. $B(x, a)$ represents how many periods a worker of eligibility status a in Tier x can receive UI benefits. $B(x, 0) = 0$ for $\forall x$ because of ineligibility. If a worker with the eligibility status a and in Tier x is unemployed for $u(> 0)$ periods, the worker receives b if $u \leq B(x, a)$, or q if $u > B(x, a)$. For further notational convenience, I define a function $\xi(x, u, a)$, which specifies the benefits received by a worker of type (x, u, a). Specifically, $\xi(x, u, a) = 0$ if $u = 0$, $\xi(x, u, a) = b$ if $0 < u \leq B(x, a)$, and $\xi(x, u, a) = q$ if $u > B(x, a)$.

The eligibility status a does not change during an unemployment spell. When a worker finds a new job and becomes employed ($u = 0$), the worker loses eligibility for UI benefits. $\pi^a_{a,a'}$ is

[1] An alternative assumption is one market for all types of workers. However, the difference in the average duration of unemployment across different income groups and the fact that the overall average job-finding rate is declining in the unemployment spell are consistent with the assumption that workers with different productivity search in different markets and thus face different job-finding rates. See Section 6 for further discussion.

the transition probability with respect to a for employed workers. An employed worker without eligibility ($a = 0$) becomes eligible ($a' = 1$) with probability $\pi^a_{0,1}$. This is a simple way to capture that a worker becomes eligible for UI benefits after working for a certain period and contributing sufficiently to the UI program. Once an employed worker becomes eligible ($a = 1$), the worker never loses eligibility until the worker loses a job, receives UI benefits, and finds a new job.

3.6. UI Benefit Extension

An extension of UI benefits gives an additional duration of UI benefits for the unemployed who are receiving or have exhausted the existing benefits under Tier x. An extension of UI benefits is modeled as increasing x (making unemployed workers eligible for a higher tier of UI benefits). Meanwhile, when workers become employed, x of the workers reverts to 0 (i.e., no additional UI benefits in the future). For simplicity, workers who are employed at the time of an extension do not benefit from extensions. In reality, some workers who lose their jobs relatively soon after an extension is implemented could receive UI benefits under an extension. However, since there is no separation decision and the separation rate will be calibrated to be low, very few employed workers benefit from an extension. Therefore, no extension for employed workers at the time of an extension is a reasonable assumption.

There are J extensions. The initial state of the economy without an extension is denoted as the extension 0, and $j = 1, 2, ..., J$ extensions are announced and implemented one by one. An extension j is defined by a triplet $\{\tau_j, \widetilde{\tau}_j, \chi_{j,t}(x, u, a)\}$. τ_j is the period in which the extension is *announced*, while $\widetilde{\tau}_j \geq \tau_j$ is the period in which the extension is *implemented*. The difference between τ_j and $\widetilde{\tau}_j$ could be important; extensions of UI benefits are typically discussed within the government before their actual implementation. Therefore, it is likely that potential beneficiaries of the extended UI benefits take into account the likelihood of their availability when they make the search intensity decision. Using $\tau_j < \widetilde{\tau}_j$, I can introduce such an *anticipation effect*. Also notice that extensions are announced and implemented sequentially, and extensions are a complete surprise when announced. Specifically, in period $t < \tau_{\overline{j}}$ for some $\overline{j}$, extensions $j = \overline{j}, \overline{j} + 1, ..., J$ are unknown to agents. Finally, $x' = \chi_{j,t}(x, u, a)$ is a function that determines how x of a type-(x, u, a) worker is changed by the extension j in period t. For example, if an extension j upgrades UI-eligible workers who are receiving UI benefits under Tier 0 to Tier 3 in period 154, $\chi_{j,154}(0, u, 1) = 3$ for $\forall u > 0$. For a period $t \neq \widetilde{\tau}_j$, x is unchanged, i.e., $\chi_{j,t}(x, u, a) = x$. For the extension 0, there is no extension by definition. Therefore, $\chi_{0,t}(x, u, a) = x$ for $\forall t, x, u, a$.

3.7. Worker's Problem

The individual state of a worker is represented by (x, h, u, a, k). The problem of an employed ($u = 0$) worker under the last announced extension j and in period t can be defined recursively as follows:

$$W_{j,t}(x, h, u = 0, a, k) = \max_{k' \geq \underline{k}} \left\{ u(c, 0) + \beta \mathbb{E}_{h',a'|h,a} \left((1 - \lambda_t) W_{j,t+1}(x', h', 0, a', k') + \lambda_t W_{j,t+1}(x', h', 1, a', k') \right) \right\} \quad (1)$$

$$s.t. \qquad c + k' = (1+r)k + w(z_t)h \tag{2}$$

$$x' = \chi_{j,t+1}(x, u, a) \tag{3}$$

Equations (2) and (3) are the budget constraint and the transition of x associated with the extension j, respectively. Notice that workers expect x to change only according to equation (3) and do not expect further extensions. Also notice that search intensity $s = 0$ for an employed worker.

The problem of an unemployed worker with the unemployment duration of $u > 0$ can be defined recursively as follows:

$$W_{j,t}(x, h, u > 0, a, k) = \max_{k' \geq \underline{k}, s \in \left[0, 1/f^h_{j,t}\right]} \left\{ u(c, s) + \beta \mathbb{E}_{h'|h} \left(f^h_{j,t} s W_{j,t+1}(0, h', 0, 0, k') + (1 - f^h_{j,t} s) W_{j,t+1}(x', h', u+1, a, k') \right) \right\} \tag{4}$$

$$s.t. \qquad c + k' = (1+r)k + \xi(x, u, a) \tag{5}$$

and equation (3). Equation (5) is the budget constraint. Notice four things: First, the tier of a worker (x) who finds a new job changes to $x' = 0$ (ineligible for an extension). Second, a' becomes 0 if the worker finds a job, while a' remains a otherwise. Third, it is necessary to know the sequence of labor market tightness $\{\theta^h_{j,t}\}_{t=\tau_j}^{\infty}$ to know the sequence of the job-finding rate. Fourth, labor market tightness depends not only on t but also on j. When solving for an equilibrium, one needs to solve for a sequence of labor market tightness for all j, since the path of labor market tightness changes when j changes.

The Bellman equations (1) and (4) characterize the optimal value functions $W_{j,t}(x, h, u, a, k)$ and associated optimal decision rules $k' = g^k_{j,t}(x, h, u, a, k)$ and $s = g^s_{j,t}(x, h, u, a, k)$. For notational convenience, let $\mathbf{M}$ be the space of an individual state, i.e., $(x, h, u, a, k) \in \mathbf{M}$. Let $\mathcal{M}$ be the Borel σ-*algebra* generated by $\mathbf{M}$, and μ the probability measure defined over $\mathcal{M}$. A type distribution of heterogeneous workers is represented by a probability space $(\mathbf{M}, \mathcal{M}, \mu)$.

3.8. Firm's Problem

The value of a matched firm can be recursively defined as follows:[2]

$$F_{j,t}(h) = (z_t - w(z_t))h + \frac{1}{1+r} \sum_{h'} \pi^h_{0,h,h'}(1 - \lambda_t) F_{j,t+1}(h') \tag{6}$$

An unmatched firm can freely enter the labor market by posting a vacancy in market h at the flow vacancy posting cost of κ. Therefore, the free-entry condition in period t and the last announced extension j for market h can be denoted as follows:

$$0 = -\kappa + \frac{d^h_{j,t}}{1+r} \sum_{h'} \pi^h_{1,h,h'} F_{j,t+1}(h') \tag{7}$$

[2] The value of a matched firm depends only on h and not on other elements of the type of the worker to which a firm is matched because of the assumption that the bargaining outcome is characterized by $w(z_t)$, which does not depend on the individual characteristics of the worker. See also the discussion in Section 3.2.

With probability $d^h_{j,t}$, an unmatched firm entering market h is matched with a worker and starts producing in the next period. The value in the next period is discounted by the interest rate r. Together with the constant returns to scale of the aggregate matching function, the labor market tightness for market h in period t under the extension j, $\theta^h_{j,t}$, is characterized by the free-entry condition (7).

3.9. Equilibrium

The economy starts with no announced extension ($j = 0$), and there are J extensions announced and implemented sequentially. Each time a new extension j is announced, the sequence of the expected future labor market tightness changes. Therefore, it is necessary to solve for the equilibrium sequence of the tightness under all $j = 0, 1, 2, ..., J$. I will first define the competitive equilibrium, then the steady-state competitive equilibrium.

Definition 1 (Competitive equilibrium) *Given a sequence of time-varying parameters $\{z_t, \lambda_t\}_{t=1}^{\infty}$, J extensions $\{\tau_j, \widetilde{\tau}_j, \chi_{j,t}(x, u, a)\}_{j=0}^{J}$, and the initial type distribution of workers μ_0, a competitive equilibrium is a sequence of labor market tightness for all markets and under all extensions $\{\theta^h_{j,t}\}_{t=\tau_j}^{\infty}$, value functions $W_{j,t}(x, h, u, a, k)$ and $F_{j,t}(h)$, optimal decision rules $g^k_{j,t}(x, h, u, a, k)$ and $g^s_{j,t}(x, h, u, a, k)$, and probability measures $\{\mu_{j,t}\}_{t=\tau_j}^{\infty}$, such that:*

1. *For all j, given $\{\theta^h_{j,t}\}_{t=\tau_j}^{\infty}$, $W_{j,t}(x, h, u, a, k)$ is a solution to the Bellman equations (1) and (4). $g^k_{j,t}(x, h, u, a, k)$ and $g^s_{j,t}(x, h, u, a, k)$ are the associated optimal decision rules for all t.*
2. *For all j, given $\{\theta^h_{j,t}\}_{t=\tau_j}^{\infty}$, $F_{j,t}(h)$ is a solution to the Bellman equation (6) for all t.*
3. *For $j = 0$, the initial measure is μ_0, while the initial measure is μ_{j-1,τ_j} for $j > 0$. For each of $j = 0, 1, 2, ..., J$, given the initial measure, the sequence of the measure of workers $\{\mu_{j,t}\}_{t=\tau_j}^{\infty}$ is consistent with the transition function implied by the stochastic processes for h and a; the job turnover process implied by the separation rate $\{\lambda_t\}_{t=1}^{\infty}$; the job-finding rate, which is computed from labor market tightness $\{\theta^h_{j,t}\}_{t=\tau_j}^{\infty}$; the optimal decision rules $g^s_{j,t}(x, h, u, a, k)$ and $g^k_{j,t}(x, h, u, a, k)$; and the transition of x characterized by $\{\chi_{j,t}(x, u, a)\}_{t=\tau_j}^{\infty}$.*
4. *For all j, the sequence of labor market tightness $\{\theta^h_{j,t}\}_{t=\tau_j}^{\infty}$ is consistent with the free-entry condition (7) for each period and market.*

Definition 2 (Steady-state competitive equilibrium) *A steady-state competitive equilibrium is a competitive equilibrium where labor market tightness, value functions, optimal decision rules, and type distribution are time-invariant.*

4. Calibration

Table 1 summarizes the calibration. One period is set as one week. Period 1 in the model corresponds to the last week of 2007, which was about the beginning of the last recession. In this section, I first calibrate the *initial steady state*, which is the starting point of the transition analysis and captures the average state of the U.S. economy, especially without the extensions. Then I discuss the calibration of the transition path in Sections 4.6 and 4.7.

Table 1: Summary of Calibration

Parameter	Description	Value
σ	Coefficient of relative risk aversion	2.0000
γ	Level parameter of disutility from search	2.1340
ϕ	Curvature parameter of disutility from search	0.9200
β	Time discount factor (weekly)	0.9976
r	Real interest rate (weekly)	0.0006
$\overline{z}$	Steady-state level of aggregate productivity	1.0000
h_1	Productivity of low-skilled workers[1]	645
h_2	Productivity of medium-skilled workers[1]	759
h_3	Productivity of high-skilled workers[1]	893
$\pi^h_{1,h_i,h_{i-1}}$	Probability of skill depreciation during unemployment (weekly)	0.0667
$\pi^h_{0,h_i,h_{i+1}}$	Probability of skill acquisition during employment (weekly)	0.0040
$\overline{w}$	Steady-state level of the bargaining outcome	0.9700
ϵ_w	Elasticity of wage with respect to productivity	0.4490
η	Level parameter of matching function	0.6068
α	Curvature parameter of matching function	0.7200
$\overline{\lambda}$	Separation rate (weekly)	0.0028
κ	Flow vacancy posting cost[1]	443
$\underline{k}$	Borrowing limit[1]	−1000
b	UI benefits[1]	541
q	non-UI benefits[1]	271
$\pi^a_{0,1}$	Probability of becoming eligible for UI benefits (weekly)	0.005033

[1] In 2005 U.S. dollars.

4.1. Preferences

I use the following separable functional form for the period utility function:

$$u(c, s) = \frac{c^{1-\sigma}}{1-\sigma} - \gamma \frac{s^{1+\phi}}{1+\phi} \tag{8}$$

The separable functional form is also employed by Chetty (2008). σ is calibrated to be 2, which is widely accepted in the literature. γ is calibrated such that the average time spent on job search is 3.8 percent of disposable time. Krueger and Mueller (2010) report that an unemployed person spends on average 32 minutes per day in job search activity.[3] The calibration strategy yields $\gamma = 2.134$. ϕ is the key determinant of how search effort responds to a change in benefits of unemployment. ϕ is calibrated to be 0.92. As will be discussed in Section 6, the responses of the average duration of unemployment to changes in the UI policy implied by the model with $\phi = 0.92$ are within the range of estimates obtained from empirical analysis. Sensitivity

[3] Disposable time per day is 14 hours. This excludes time for sleep and other personal care activities.

of the main results under different values of ϕ is investigated in the separate appendix. The discount factor, β, is calibrated to be 0.9976. With $\beta = 0.9976$, 40.2 percent of the unemployed have either zero or a negative amount of assets (the 2005 wave of the Panel Study of Income Dynamics (PSID)). The weekly interest rate is set at $r = 0.0006$, which corresponds to an annual interest rate of 3 percent.

4.2. Technology and Wage Determination

$\overline{z}$, the steady-state z_t, is normalized to 1. I use three ($H = 3$) skill levels. A drop of one level is intended to capture the average skill depreciation during an unemployment spell, and a drop of two levels represents the skill depreciation of the long-term unemployed. The step size of h is set at 0.15, i.e., a drop of a skill level corresponds to a 15 percent loss of wages after obtaining the next job. The step size is consistent with Farber (2011), who reports that job losers experience on average about 15 percent of real weekly earnings. Jacobson et al. (1993) and Kambourov and Manovskii (2009) report similar numbers. The probability of skill depreciation is set at 1/15, based on the average duration of an unemployment spell. As for the skill accumulation, the probability of climbing up to the next skill level is set at 1/250. Kambourov and Manovskii (2009) report that the first 5 years of occupational tenure are associated with an increase in wages of 12-20 percent. The productivity level of the medium skill level h_2 is set at 759, which corresponds to the median wage of workers in the Current Population Survey (CPS) during 2000-2010.

The wage function takes the form of $w(z) = \exp(\log \overline{w} + \epsilon_w \log z)$, where $\overline{w}$ represents the share of output for the worker in the steady state, and ϵ_w represents the elasticity of the average wage with respect to aggregate productivity. I set $\overline{w} = 0.97$, which corresponds to the large size of workers' earnings relative to the firm's profits. The calibration of both Shimer (2005) and Hagedorn and Manovskii (2008) implies a similar value of $\overline{w}$. As for ϵ_w, Hagedorn and Manovskii (2008) report that a 1 percent increase in labor productivity is associated with a 0.449 percent increase in real wages.[4]

4.3. Labor Market

The matching function takes the Cobb-Douglas form of $M = m(S, V) = \eta S^{\alpha} V^{1-\alpha}$. η is calibrated such that the steady-state unemployment rate is 4.77 percent, which is the average during 2005-2007. The calibration procedure yields $\eta = 0.6068$. The curvature parameter α is set at 0.72, as in Shimer (2005). I will investigate the sensitivity of the main results with respect to α in the separate appendix for the following two reasons. First, there is a wide range of estimates of α. According to Petrongolo and Pissarides (2001), estimates of α that are obtained using a variety

[4] Instead of assuming a particular bargaining protocol and calibrating the parameters associated with the bargaining to replicate the elasticity, I assume the wage function directly. However, the calibration implicitly assumes that the real wage is moderately sticky ($\epsilon_w = 0.449$), and the large share of the surplus is taken by the worker ($\overline{w} = 0.97$). This is achieved in Hagedorn and Manovskii (2008) by setting the flow utility of unemployment close to that of employment, and allowing high bargaining power for the firm in the generalized Nash bargaining. The assumption of a high value for non-monetary benefits of unemployment (see Section 4.5) is consistent with this interpretation.

of methods and data range between 0.12 and 0.81.[5] Second, estimates for α are for a model without a search intensity decision. The weekly separation rate in the steady state, $\overline{\lambda}$, is set at 0.0028. This is the average weekly transition probability from employment to unemployment in CPS during 2005-2007. κ is calibrated to be 443, which is 0.584 of average weekly labor productivity. The ratio (0.584) is computed by Hagedorn and Manovskii (2008).

4.4. Financial Market

The borrowing limit $\underline{k}$ is set at -1000, which generates median asset holdings of 2500. This is close to the median liquid asset holdings of $2600 reported by Chetty (2008). The level of the borrowing constraint is also close to the median non-housing debt among the unemployed in the 2005 PSID. I will conduct a sensitivity analysis with respect to $\underline{k}$ in the separate appendix, since arguments can be made that the borrowing constraint might be too lax or too strict. On the one hand, the median asset holdings of newly unemployed workers in the model ($2600) are higher than those in the data reported by Gruber (2001) ($1500), which implies that the borrowing constraint has to be more strict. On the other hand, Bils et al. (2011) set the borrowing constraint to be equivalent to labor income of six months, which suggests the opposite. However, the main results of the paper are shown to be robust to the choice of the borrowing constraint in the separate appendix.

4.5. Unemployment Insurance Program

In calibrating the level of unemployment benefits in the model, I include both monetary and non-monetary benefits of unemployment. The UI-eligible unemployed are assumed to receive $b = 541$, which is 0.735 of the average labor income. This replacement rate is the sum of the mean replacement rate of the UI-benefits across states (0.435) and the non-monetary benefits of unemployment ($\rho = 0.3$).[6] $\rho = 0.3$ is consistent with the value of leisure obtained by Nakajima (2012), and the total replacement rate of 0.735 is close to the value calibrated by Costain and Reiter (2006).[7] The separate appendix includes the results of a sensitivity analysis with respect to ρ.

The UI-ineligible unemployed receive $q = 271$, which is the sum of the monetary benefits that UI-ineligible unemployed can receive and the non-monetary benefits of unemployment. As for the former, I use the average weekly benefits under the food stamp program (Supplemental Nutrition Assistance Program) per family in 2005, which is $50.[8] The latter (non-monetary benefits of unemployment) is the same as for the UI-eligible unemployed ($\rho = 0.3$ of average labor income).

In the initial steady state, there is no UI benefit extension, i.e., $x = 0$ for all workers. $B(x = 0, 1)$ is set at 26 weeks, which is the duration of regular UI benefits.

The probability of a UI-ineligible employed worker becoming eligible for UI benefits ($\pi^a_{0,1}$) is

[5] See Table 3 of Petrongolo and Pissarides (2001).

[6] For the replacement rate of the UI-benefits, I take a simple average of the replacement rates across all states shown in Table A1 of Gruber (1998). The median replacement rate is 0.422.

[7] Hagedorn and Manovskii (2008) find that a large ρ is consistent with the observed high volatility of unemployment and vacancies. Bils et al. (2011) and Nakajima (2012) echo the finding.

[8] It is computed using the average monthly benefit per person under the food stamp program ($92.6) and the average number of family members (2.3).

Table 2: **Extensions of Unemployment Insurance Benefits in the Model**

No (j)	Period ($\widetilde{\tau}_j$)	Year/Month/Week	Description
0	1	2007/Dec/5th	Initial state. No extension.
1	27	2008/June/5th	Tier 1 is introduced.
2	48	2008/Nov/4th	Tier 2 is introduced.
3	60	2009/Feb/3rd	Tier 3 is introduced.
4	74	2009/May/4th	Tier 4 is introduced.
5	98	2009/Nov/2nd	Tier 5 is introduced.
6	112	2010/Feb/3rd	Tiers 1-5 UI benefits extended (+1 tier).
7	126	2010/May/4th	Tiers 1-5 UI benefits extended (+1 tier).
8	140	2010/Aug/5th	Tiers 1-5 UI benefits extended (+1 tier).
9	154	2010/Dec/1st	Tiers 1-5 UI benefits extended (+3 tiers).

calibrated to match the average proportion of unemployed workers who are receiving UI benefits. The proportion typically fluctuates between 30 percent to 45 percent, and it is strongly countercyclical. The cyclicality is due to the cyclicality of the proportion of firings, which itself is countercyclical, and the extensions of UI benefits, which are made available during severe recessions. In the recent downturn, the proportion of UI benefit recipients among all unemployed workers increases dramatically, from around 36 percent in 2005-2007 to 66 percent in 2008-2009, with the highest at about 70 percent. Since I am interested in measuring the effect of UI benefit extensions on the unemployment rate during the recent downturn, and there is no endogenous mechanism in the model to generate the increase in the proportion of UI-eligible unemployed during downturns except for that due to extensions, I calibrate $\pi^a_{0,1}$ such that approximately 70 percent of unemployed workers receive UI benefits when the proportion is at its highest along the baseline transition path. The calibration strategy generates $\pi^a_{0,1} = 0.0050$.

4.6. UI Benefit Extensions

The UI benefit extensions in the model are carefully designed to mimic the ongoing extensions of UI benefits described in Section 2. Specifically, as in the actual UI extensions, I assume five tiers of extended UI benefits, in addition to the regular UI benefits (Tier 0). Tier 0 (regular UI) is available for all workers and provides up to 26 weeks of benefits. This is the only tier available in the initial steady state. Tiers 1 to 4 correspond to Tiers 1 to 4 of the EUC08. Tier 5 in the model corresponds to the EB program, which was made available to most states during the recent downturn and can be used after all benefits under the EUC08 are exhausted. After averaging the duration of Tier 4 and Tier 5 in the model, the five extra tiers provide unemployed workers an additional 20, 14, 13, 13, and 13 weeks of UI benefits, respectively. In total, an unemployed worker who is eligible for up to Tier 5 benefits can receive 99 weeks of UI benefits, as in the current U.S. economy.

Extensions of UI benefits in the model capture the key characteristics of EUC08 and its subsequent expansions and extensions in a stylized manner. Table 2 summarizes the extensions in the

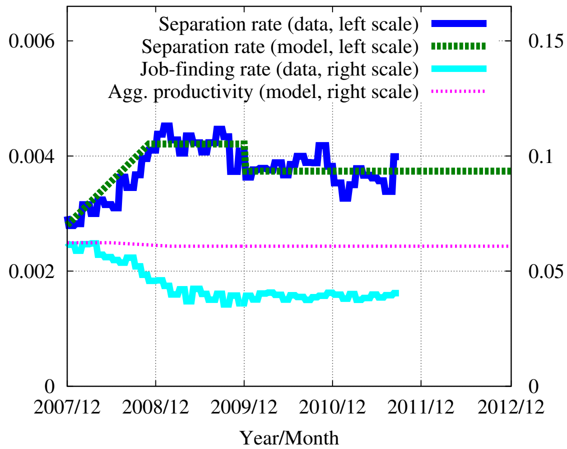


Figure 1: Separation Rate and Job-Finding Rate.

model. There are nine extensions in the model, as in the U.S. Each of the first five extensions introduces an additional tier, one by one. For example, when Tier 2 is introduced in period 48, all the unemployed who are eligible for Tier 1 benefits become eligible for Tier 2 benefits as well. Meanwhile, the unemployed who are eligible only for Tier 0 (regular) benefits become eligible for Tier 1 benefits. Workers employed at the time of the extension do not become eligible for any extended benefits. Similar things take place until the fifth extension. The dates of the first five extensions roughly correspond to the dates of the original EUC08, its expansions, and the dates when the two levels of the EB program are activated.

The remaining four (6th to 9th) extensions in the model made the benefits under Tiers 1-5 available to more of the unemployed without adding new tiers, as in the U.S. economy. Although the intervals between each extension in the U.S. were not uniform, I assume that extensions in the model take place every 14 weeks. The 9th extension in the model, which takes place in period 154, corresponds to the 9th extension implemented in the U.S. in December 2010. In terms of the length of extensions, I assume that the 6th to 8th extensions add one more tier to unemployed workers, while the last (9th) extension gives three additional tiers. In the U.S., the 6th to 8th extensions pushed back the deadline for applying for a new tier by 11.0 weeks on average, while each of the extensions added 14.6 weeks of UI benefits on average. Therefore, it is reasonable to assume that each of the 6th to 8th extensions allows unemployed workers to enjoy one additional tier. As for the 9th extension, the deadline for applying for a new tier was pushed back substantially, for 55 weeks. Since 55 weeks roughly corresponds to three extra tiers, the 9th extension in the model is assumed to entitle unemployed workers to three additional tiers.

Each extension is announced one month (4 periods) prior to its implementation. I will investigate the importance of the announcement effect by implementing an alternative scenario in which UI benefit extensions are not announced in advance.

4.7. Transition Path

In the transition analysis, the separation rate, λ_t, and aggregate productivity, z_t, change over time in addition to UI benefit extensions. Two remarks are worth making. First, the path of both the separation rate and aggregate productivity is revealed at the beginning of the transition (period 1). In other words, it is a perfect foresight equilibrium with respect to the separation rate and aggregate productivity. Although it is more reasonable that the severity of the downturn was not perfectly understood in period 1 (December 2007), it is computationally difficult to assume that the recession was gradually revealed, in addition to multiple policy changes. Second, although the separation rate shock and the aggregate productivity shock are two separate shocks in the model, the distinction between the two is technical; the two time-varying parameters together represent the severe economic downturn.

Figure 1 compares the separation rate computed using the CPS, and its smoothed version, which is used as a model input. The separation rate increased sharply from the end of 2007 to the end of 2008 and stayed elevated until 2011. The input used for the model captures such a trend during 2007-2011. From 2012 on, the separation rate in the model is assumed to remain elevated until the end of 2012, before gradually coming back to the steady-state level by the end of 2014. Figure 1 also exhibits the job-finding rate during 2007-2011, calculated from the CPS. The job-finding rate dropped sharply from early 2008 to early 2009 and has remained low since then. In order to generate such dynamics of the job-finding rate, aggregate productivity is assumed to drop from the end of 2007 until early 2009, remain at the low level until the end of 2012, and gradually recover to the steady-state level by the end of 2014. Figure 1 shows the path of aggregate productivity as well. The low level of aggregate productivity is calibrated such that, in the baseline case, the unemployment rate goes up to around 10 percent in the fall of 2009, which is the highest level observed during the recent downturn. In the baseline transition analysis, it turns out that a 1.1 percent drop in aggregate productivity generates such dynamics of the unemployment rate. The size of the decline in aggregate productivity is significantly smaller than the size of the drop in the job-finding rate for three reasons. First, firms are forward-looking and the long recession has a compound effect on the firm's expected future value. Second, the other inputs – higher separation rates and UI benefit extensions – already contribute to a large increase in the unemployment rate. Third, as in Hagedorn and Manovskii (2008), a small change in aggregate productivity is amplified to have a large effect on unemployment.

5. Computation

The model is solved numerically. While an equilibrium of a heterogeneous-agent model with a deterministic transition has been solved, for example, by Conesa and Krueger (1999), the innovation of the current paper is that there are multiple policy changes (actually nine of them) along the deterministic transition path, and each policy change is announced in advance. The details of the computation, including how to deal with these novel features, are discussed in the separate appendix.

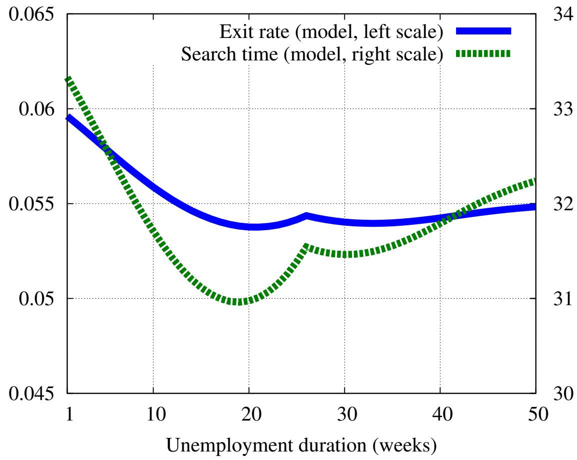


Figure 2: Exit Rate and Search Time: All Unemployed Workers.

6. Results: Steady State

Section 6 studies the properties of the initial steady-state economy and then the effects of changes in the UI policy using steady-state comparisons. Section 7 uses the economy with an equilibrium transition to investigate the effect of the UI benefit extensions on the unemployment rate.

6.1. Properties of the Initial Steady State

Table 3 summarizes the results. Let's start from the first and second columns, which compare the data and the initial steady-state economy. The unemployment rate is 4.77 percent in the model, which is the U.S. average during 2005-2007. The proportion of unemployed workers receiving UI benefits over the total number of unemployed workers is 51 percent. As discussed in Section 4.5, the proportion is higher than in the data (36 percent), but it is necessary to replicate that the proportion reaches 70 percent during the downturn in the transition simulation.[9] The mean unemployment duration of all unemployed workers is 18.2 weeks, which is slightly longer than the average of 2005-2007 in the data (17.4 weeks).

The model replicates reasonably well how the exit rate (transition probability from unemployment to employment) and the time spent for search activity change over the unemployment spell in the data. As for the empirical exit rate profile, Fujita (2010) shows that it declines quickly for the first ten weeks and remains low except for the temporary spike around the 26th week.[10] Figure 2 exhibits the exit rate profile generated by the model. The model successfully captures

[9] Although policy experiments based on the steady-state comparisons (Section 6.2) are used to calibrate the search elasticity parameter, ϕ, having a higher proportion of UI recipients among the unemployed in the baseline steady state is not a serious problem, because ϕ is calibrated such that the model's responses of the average duration of unemployment *among the UI-eligible* to changes in the duration or amount of UI benefits are within the range of empirical estimates.

[10] Notice that there is a difference between the exit rate from unemployment to employment, and the unconditional exit rate, which includes the exit from the labor force. The shape of the exit rate profile is similar, but the spike at around the 26th week is more pronounced for the latter, as seen in Meyer (1990), since many workers exit from unemployment to out-of-the-labor-force when the regular benefits expire after the 26th week.

Table 3: Steady-State Effect of Changes in Unemployment Insurance Policy

Economy	Data	Base	+10%	+20 weeks	+73 weeks	$+\infty$ weeks
UI replacement rate[1]	0.4350	0.4350	0.5350	0.4350	0.4350	0.4350
Duration of UI benefits[2]	26	26	26	46	99	∞
Unemployment rate (U)	0.0477	0.0477	0.0489	0.0520	0.0627	0.0770
UI-eligible		0.0319	0.0332	0.0364	0.0473	0.0618
Receiving benefits	0.0173	0.0242	0.0248	0.0324	0.0462	0.0618
(% of U)	36.17	50.70	50.64	62.37	73.63	80.25
Exhausted benefits		0.0077	0.0084	0.0040	0.0011	–
UI-ineligible		0.0158	0.0157	0.0156	0.0154	0.0152
Mean duration[2]	17.40	18.21	18.55	20.02	26.44	37.46
Among UI-eligible		18.68	19.18	21.24	29.47	42.45
Among UI-ineligible		17.24	17.21	17.16	17.15	17.16
Aggregate search effort[3]		1.8123	1.8109	1.8062	1.7884	1.7623
Average search effort[4]	32.0	32.0	31.1	29.2	24.0	19.2
Vacancies[3]		43.027	42.925	42.715	42.070	41.355
Market tightness[5]		1.0000	0.9984	0.9961	0.9909	0.9885
Job-finding rate	0.0559	0.0559	0.0545	0.0511	0.0419	0.0336
Separation rate	0.0028	0.0028	0.0028	0.0028	0.0028	0.0028
Median asset[6]	2600	2500	1800	1300	900	1000
Mean labor income[6]	793	793	792	791	788	787
Prop of low skilled		0.2025	0.2061	0.2128	0.2311	0.2471
Prop of medium skilled		0.2162	0.2168	0.2168	0.2163	0.2137
Prop of high skilled		0.5813	0.5771	0.5703	0.5526	0.5392

[1] Replacement rate of the monetary UI-benefits.
[2] In weeks.
[3] Multiplied by 1000.
[4] In minutes per day.
[5] Normalized such that it is one in the baseline model.
[6] In 2005 U.S. dollars.

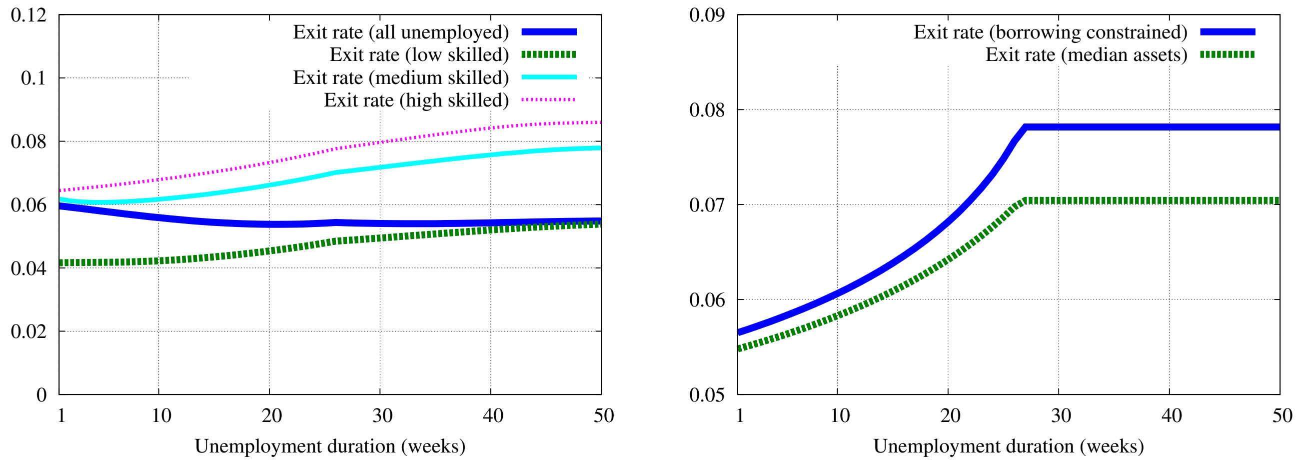
the qualitative features of the empirical exit rate profile, although the decline of the exit rate at the beginning of an unemployment spell and the spike at around the 26th week are much less pronounced than those in the data. In order for the model to replicate both qualitatively and quantitatively the exit rate profile, features such as richer heterogeneity, temporary layoffs, stock-flow matching, and learning might be needed. Moreover, the empirical spike at around the 26th week might be partly due to rounding up when reporting. The rounding-up hypothesis is supported by the fact that the exit rate also temporarily rises at around one year.

As for the search time profile, Krueger and Mueller (2010, 2011) provide valuable empirical evidence, but it is not easy to reconcile the findings of the two studies. Let's start with the former. Krueger and Mueller (2010) report that the time for job search is around 50 minutes in the first 14 weeks of unemployment and declines to about 30 minutes before it rises to 70 minutes at the 26th week. The search time declines again after the 26th week. The search time profile generated by the model is qualitatively consistent with the empirical counterpart; the search time declines until around the 20th week, goes up sharply around the 26th week, and declines after the 26th week. However, quantitatively the changes in the model over the unemployment spell are small compared with the data. On the other hand, in their recent paper, Krueger and Mueller (2011) argue that the time for job search declines for all cohorts regardless of the duration of unemployment, according to their surveys conducted in the fall of 2009.[11] This is hard to reconcile with the findings of Krueger and Mueller (2010) and the exit rate profile that I discussed above. However, their interpretation is based on the assumption that the time effect (the recession is discouraging all the unemployed from searching) is small, while it is difficult to separately identify the time effect and the unemployment duration effect. Under the alternative interpretation that the time effect is significant, a different picture emerges; their figures suggest that the time for job search is relatively stable, or even increasing over the unemployment spell, but the time effect is pushing the time for job search down for all cohorts during the survey period. The search time profile shown in Figure 2, which is fairly stable over the unemployment spell, is consistent with such an interpretation. Indeed, a regression with time spent searching for a job as the dependent variable, and unemployment duration and unrestricted person fixed effects as explanatory variables, but without time effects, as in Krueger and Mueller (2011), generates a negative coefficient (-0.39 minute per additional week of unemployment) for unemployment duration as in Krueger and Mueller (2011), using artificial data generated by the model.

Notice that it is not easy for a model of job search to generate an exit rate or profile of search time that is not monotonically increasing. Conditional on the type of worker, the incentive for search is increasing in the unemployment spell as the remaining duration of UI benefits keeps shrinking and the assets keep depleting. The reason why the profiles of the exit rate and the time for job search in the model are not monotonically increasing is the composition effect. Figure 3 (a) exhibits the exit rate for each skill group as well as the exit rate of all unemployed workers. Although the exit rate profile is upward sloping conditional on the skill type, as unemployed workers experience skill depreciation, the exit rate profile keeps shifting down. Notice that, in Figure 3 (a), the overall exit rate is close to the exit rate among the medium skilled for short unemployment spells, while the exit rate is mainly determined by that of the low skilled for long unemployment spells. This is because the average skill level depreciates from medium skill to low skill during an unemployment spell.

Figure 3 (b) shows how exit rates are affected by asset holdings. When there is a borrowing constraint, unemployed workers are more desperate in searching if they are close to the constraint. Chetty (2008) emphasizes this *liquidity effect* by distinguishing it from the standard moral hazard effect. In Figure 3 (b), the search intensity and the exit rate are higher for the

[11] See Figure 3.1 of their paper.



(a) Skill levels

(b) Asset holding

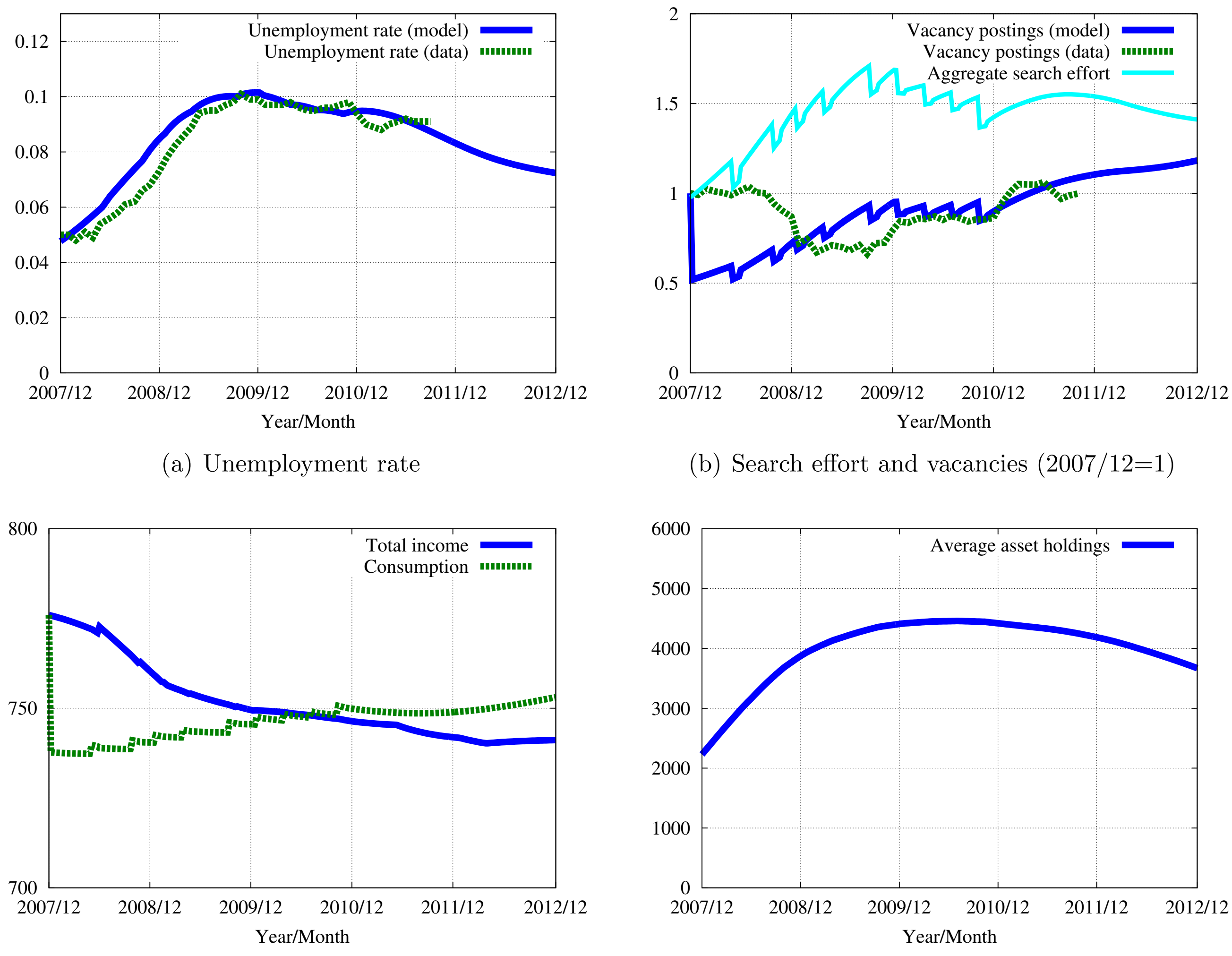
Figure 3: Weekly Exit Rate: Decomposition.

medium-skilled UI-eligible unemployed at the borrowing constraint (line above) than the same type of the unemployed with median asset holdings (line below). Conditional on the skill type, the overall exit rate goes up with unemployment duration partly because the unemployed exhaust their assets. Notice that this property implies that the slope of the exit rate is steeper if the borrowing constraint is tighter. If the model is calibrated so that the unemployed are more likely to be borrowing constrained, holding all else fixed, the average duration of unemployment in the model will be shorter (and closer to the data), but the slope of both the exit rate and the search time will be higher during the unemployment spell, which could make them inconsistent with the data.

6.2. Policy Experiments: Changes in UI Benefit Policy

The third to sixth columns of Table 3 summarize the effects of changing the UI benefit policy. The third column shows the effect of increasing the replacement rate of monetary UI benefits by 10 percentage points while keeping the duration of UI benefits at 26 weeks. I use 10 percentage points because various empirical estimates are available for the response of the average unemployment duration to a 10-percentage-point increase in the replacement rate of UI benefits. Existing estimates are in the range of a 0.5-1.5 week increase in the average duration among the UI-eligible unemployed. All of the available estimates are obtained by estimating the hazard function out of unemployment, but the difference arises because of the data, estimation methodology, and the sample period. Hamermesh (1977) concludes that "the best estimate – if one chooses a single figure – is that a 10-percentage-point increase in the gross replacement rate leads to an increase in the duration of insured unemployment of about half a week when labor markets are tight." Moffitt and Nicholson (1982) find that a 10-percentage-point increase in the replacement rate is associated with an increase in unemployment duration of about 0.8-1.0 week. Meyer (1990) estimates the effect to be an increase of 1.0-1.5 weeks of average unemployment duration. Moffitt (1985) obtains the effect to be a 0.5 week increase in potential duration. In the baseline model, the mean duration of unemployment among UI-eligible unemployed workers increases by about 0.5 week, from 18.7 to 19.2 weeks. The response of the average duration is at the lower bound of the range of empirical estimates of 0.5-1.5 weeks. This makes the calibration conservative. The longer unemployment duration is caused by a disincentive effect; more generous UI benefits discourage the search efforts of UI-eligible unemployed. Since UI-ineligible unemployed are not directly affected by the policy change, the mean duration of unemployment of UI-ineligible workers does not change. The unemployment rate increases from the baseline rate of 4.77 percent to 4.89 percent. While the number of unemployed workers increases, the average search effort declines (from 32 to 31 minutes per day), resulting in a slight decline in the aggregate search effort (0.08 percent). Accordingly, both the number of vacancies (0.24 percent) and labor market tightness (0.16 percent) decline. More generous UI benefits also discourage precautionary savings. Median asset holdings drop from $2500 to $1800. Although I do not consider the general equilibrium effect from declining aggregate savings, this could have a negative effect on output, in addition to the one caused by a lower employment rate.

The fourth to sixth columns show the effects of increased duration of UI benefits, by 20, 73, and infinite weeks, respectively. The 73-week increase is chosen because the addition of 73 weeks makes the total duration 99 weeks. This experiment is intended to show that a steady-state analysis can be misleading because the ongoing extensions are very different from the steady state where all workers receive 99 weeks of UI benefits whenever they become unemployed. On the empirical side, existing estimates are in the range of a 0.08-0.2 week increase in average unemployment duration in response to a 1-week increase in the duration of UI benefits. Moffitt (1985) estimates the effect of a 1-week extension of UI benefits to be about a 0.15 week increase in the average unemployment spell of UI recipients. Moffitt and Nicholson (1982) estimate the effect to be 0.1 week. The estimate obtained by Katz and Meyer (1990) is a 0.16-0.20 week increase. More recently, Card and Levine (2000) obtain the smallest estimate of 0.08 week. To compare the empirical estimates with the output of the model, let's look at the 20-week increase. The average duration of unemployment among UI-eligible unemployed workers increases by about 2.5 weeks, from 18.7 to 21.2 weeks. This means that a 1-week increase of UI benefit duration is associated with an increase in the average UI-insured duration of 0.13 week. This response of the average duration is approximately in the middle of the range of empirical estimates of 0.08-0.2. Although the response of the calibrated baseline model to a 10-percentage-point increase in the replacement rate of UI benefits is at the lower bound of the available empirical estimates, I put more weight on matching the model's response to an increase in the duration of UI benefits, because the focus of the paper is the extended UI benefits. The unemployment rate goes up to 5.2 percent. Median asset holdings decline substantially from $2500 to $1300, as the precautionary saving motive is weakened by the longer availability of UI benefits. A longer duration of unemployment shifts the composition of skilled and unskilled workers; as the more generous UI benefit duration discourages the search effort and induces unemployed workers to remain unemployed longer, more workers lose their skills during unemployment spells. As a result, the proportion of high-skilled workers in the economy drops from 58 percent to 57 percent, which lowers the average wage of workers from $793 to $791. When the UI benefit duration is further increased to 99 weeks, and then infinite weeks, the effects observed in the 20-week extension are further strengthened. In the steady-state comparison, an increase in the UI benefit duration from 26 to 99 weeks increases



(a) Unemployment rate

(b) Search effort and vacancies (2007/12=1)

(c) Income and consumption

(d) Average asset holdings

Figure 4: Transition Dynamics (2007/12-2012/12).

the unemployment rate by 1.5 percentage points, from 4.8 percent to 6.3 percent. In the limit case in which UI benefits are available permanently, the unemployment rate soars to 7.7 percent.

7. Results: Transition Dynamics

Section 7.1 gives an overview of the properties of the baseline transition path. Section 7.2 investigates the effects of the UI benefit extensions on the unemployment rate. Finally, Section 7.3 covers a variety of counterfactual experiments.

7.1. Transition Dynamics of the Baseline Economy

Figure 4 summarizes the baseline equilibrium transition path generated by the model between December 2007 and December 2012. Panel (a) of Figure 4 compares the unemployment rate in the data and the one generated by the model. They are close to each other; both increase sharply between the end of 2007 and 2009 and have remained high at slightly below 10 percent since then. The closeness is not a result; the aggregate productivity is calibrated to achieve it. As there are no more UI benefit extensions, and both the aggregate productivity and separation rate are assumed to gradually revert to their respective steady-state levels, the unemployment rate in the model gradually goes back to its steady-state level of 4.77 percent. The unemployment rate of the model increases faster than in the data in 2008 because the future path of aggregate productivity is completely revealed at the beginning of the transition and thus firms reduce the number of vacancy postings faster than in the data. If the future path of aggregate productivity is revealed gradually, the unemployment rate in the model rises more slowly and thus fits the empirical counterpart better.

Panel (b) shows the number of vacancies posted in the model and in the data and the aggregate search effort. The number of vacancies in the data is the Help-Wanted OnLine Data Series compiled by the Conference Board. All data series are normalized such that the value is one in December 2007. In the model, the number of vacancies drops significantly at the beginning of the transition, when the future path of aggregate productivity is revealed. Since then, the number of vacancies has gradually recovered. Surprisingly, the model is successful in replicating the path of the number of vacancies in the data, except for the gradual decline at the beginning. The number of vacancies in the model would track the number of vacancies in the data more closely if the future aggregate productivity is gradually revealed. Both in the data and in the model, although the number of vacancies has been recovering after the initial drop, the unemployment rate has remained high. This is because the successive extensions of UI benefits keep the unemployment rate elevated. The hump shape of the aggregate search effort is less pronounced than the hump shape of the unemployment rate, because the individual search effort is decreasing while the unemployment rate is rising. Finally, notice that the aggregate search effort and the number of vacancies exhibit multiple kinks, each of which corresponds to each announcement of a new UI benefit extension.

Panel (c) of Figure 4 shows the path of average income and consumption. Average income declines gradually as more workers become unemployed and receive unemployment benefits instead of labor income. Moreover, due to the skill depreciation, the proportion of high-skill workers declines from 58 percent at the end of 2007 to 49 percent at the bottom, while the proportion of low-skill workers increases from 20 percent to 28 percent. As a result, average labor income declines from \$793 in the initial steady state to \$767 at its bottom. Not only does skill depreciation reduce the aggregate stock of skills in the economy, but it also reduces the job-finding rate of the unemployed who lose skills and further prolongs the average unemployment duration. Average consumption drops immediately when the recession is revealed. As the economy approaches the end of the recession and the unemployment rate recovers, precautionary savings decline and average consumption gradually comes back to the pre-recession level. Notice that average consumption ticks up each time a new UI benefit extension is announced, since the expected lifetime income, especially of the unemployed, increases with an extension (UI-benefits are higher than non-UI-benefits).

Panel (d) shows the path of mean asset holdings. Mean asset holdings increase from the initial

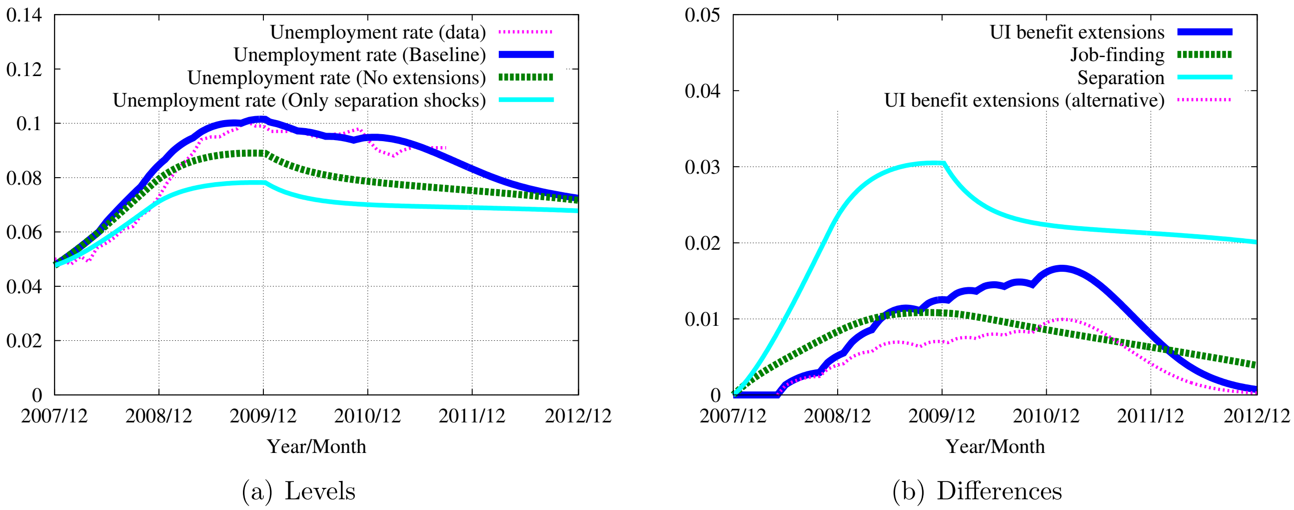


Figure 5: Decomposition of the Unemployment Rate Dynamics.

value of \$2228 to \$4460 during 2008-2010 and then gradually revert to the initial steady-state level after 2010. The initial increase is an optimal response of precautionary savings to a higher risk of separation and a longer unemployment spell. It is interesting to note that the U.S. personal saving rate went up sharply from 2.2 percent during 2005-2007 to 5.3 percent during 2008-2010, and was declining in 2011 with the recovery of the economy. The increased savings are often attributed to the deleveraging from the state of excess borrowing, but this increase can also be rationalized as the increased precautionary savings in response to a higher labor market risk.

7.2. Contribution of UI Benefit Extensions on Unemployment

In order to measure the contribution of UI benefit extensions, the time-varying separation rate, and time-varying aggregate productivity, to the unemployment rate, I first simulate the baseline economy without the UI benefit extensions. The difference in the unemployment rate between the baseline economy and the counterfactual economy without the extensions gives the contribution of UI benefit extensions to the unemployment rate. Next, I further replace time-varying aggregate productivity by its steady-state value and simulate the economy again. The difference in the unemployment rate between the two counterfactuals provides the measure of the contribution of aggregate productivity to the unemployment rate. Finally, if all three elements are turned off, the unemployment rate stays at the steady-state level. Therefore, the difference in the unemployment rate between the counterfactual economy with only the time-varying separation rate and the steady-state unemployment rate gives the contribution of the time-varying separation rate to the unemployment rate. Figure 5 exhibits the decomposition. Panel (a) shows the levels of the unemployment rate under the baseline and the counterfactuals, while Panel (b) shows the contribution of the three elements. On average between August 2008, when the unemployment rate in the data reached 9.7 percent, and September 2011, the contribution of the nine UI benefit extensions is 1.4 percentage points, or 29 percent of the overall increase in the unemployment rate (4.8 percentage points, from 4.8 percent during 2005-2007 to 9.6 percent during 2009-2011).

The contribution of economic conditions is the remaining 3.4 percentage points. Among the 3.4 percentage points, 2.5 percentage points (52 percent of the overall increase in the unemployment rate) are attributed to the rising separation rate, while 0.9 percentage point (19 percent) is attributed to the stagnating aggregate productivity.

The changes in the relative contribution of the three elements over time are striking. The initial increase in the unemployment rate is mainly due to the economic environment, in particular, the rising separation rate, while the UI benefit extensions are yet to be introduced. However, since the UI benefit extensions were enacted, the contribution of the UI benefit extensions continue to rise. In the first quarter of 2011, the contribution of the UI benefit extensions reaches 1.7 percentage points, while the contributions of the separation rate and aggregate productivity are 2.2 and 0.8 percentage points, respectively. The successive renewal of the UI benefit extensions keeps the unemployment rate elevated in 2011 even though the number of vacancies posted continues to recover (see Figure 4 (b)), and the separation rate has shifted down since 2010 (see Figure 1).

The effect of the UI benefit extensions on the unemployment rate is significantly affected by economic conditions. This is shown in Figure 5 (b) as "UI benefits extensions (alternative)." It shows the changes in the unemployment rate when only the UI benefit extensions are implemented without changing the separation rate or aggregate productivity from their steady-state levels. The effect of the extensions on the unemployment rate is measured to be smaller than the number computed above. On average between August 2008 and September 2011, the contribution is 0.8 percentage point instead of 1.4 percentage points. The main reason is that a higher separation pushes more workers into unemployment, which makes the effect of discouraged search efforts on the unemployment rate greater.

Remember that the effect of extending the duration of UI benefits up to 99 weeks on the unemployment rate is 1.5 percentage points in the steady-state analysis (Table 3). Although it is close to the contribution of the UI benefit extensions obtained from the baseline transition analysis (1.4 percentage points), it does not mean that the transition analysis is not adding much to the steady-state analysis. The comparable number for the steady-state analysis is 0.8 percentage point, which is obtained by just introducing the UI benefit extensions but without changing the separation rate or aggregate productivity. The difference implies that the unemployment rate would be 0.6 percentage point higher than it is already if the UI benefit of up to 99 weeks is made permanent. In other words, not surprisingly, the steady-state analysis is overstating the effect of the UI benefit extensions by not taking into account the gradual and temporary nature of the extensions.

7.3. Policy Experiments: Counterfactual UI Benefit Extensions

The extension agreed between the President and Congress in December 2010 did not increase the maximum duration of UI benefits (which remains at 99 weeks), but it substantially pushed back the deadline for applying for a higher tier (see Section 4.6). What is its effect on the unemployment rate? To quantify the effect, I run a counterfactual experiment in the model economy where the December 2010 extension in the model is not implemented. Figure 6 compares the dynamics of the unemployment rate under the baseline transition path with all extensions,

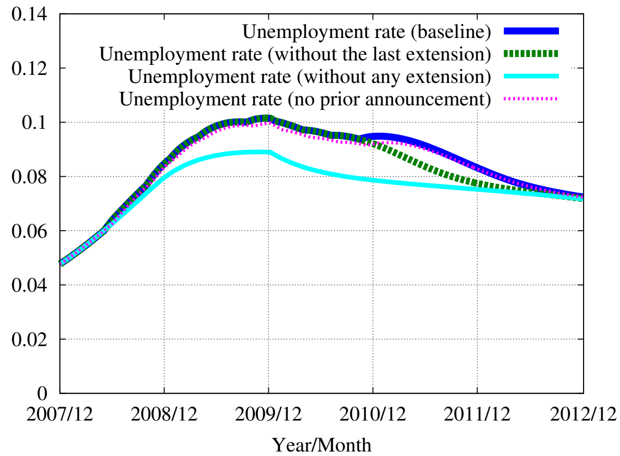


Figure 6: Unemployment Rate: Counterfactual experiments.

and under the counterfactual transition path, without the December 2010 extension. In the figure, when labor market conditions improve and the economy reverts to its steady state, the December 2010 extension keeps the unemployment rate higher during the transition. The difference in the unemployment rate is 0.6 percentage point on average in 2011. Needless to say, in evaluating the extension, it is important to compare the cost of a slower recovery shown here with the insurance provided to those who are unemployed and fiscal implications. This is left for future research.

The extreme case in which no UI benefit extension is implemented is also shown in Figure 6. In this scenario, the highest unemployment rate during the recent downturn would have been around 9 percent instead of 10 percent. In 2011, the unemployment rate under the counterfactual scenario would be around 7.7 percent instead of the baseline rate of 9.0 percent.

Finally, how large is the announcement effect? The baseline assumption is that each UI benefit extension is announced 4 weeks before its implementation, which allows potential beneficiaries to start reacting (reducing search time) before the actual implementation. Figure 6 also exhibits the counterfactual simulation in which there is no prior announcement for all extensions. The difference between the baseline case in which extensions are announced 4 weeks in advance and the counterfactual case without announcements is relatively minor; the difference is between 0.1 to 0.3 percentage point in the unemployment rate.

8. Conclusion

This paper quantifies the effect of UI benefit extensions on the unemployment rate using a calibrated structural model that features job search and consumption-saving decisions, skill depreciation, and UI eligibility. With a structural model, I can capture the effect of the UI benefit extensions on the unemployment rate and other macroeconomic aggregates, carefully taking into account the gradual and temporary nature of the recent extensions. Moreover, a structural model enables counterfactual experiments. The extensions of UI benefits are found to have contributed to an increase in the unemployment rate of 1.4 percentage points, which is 29 percent of the observed increase in the unemployment rate (4.8 percentage points). Among the remaining 3.4

percentage points, 2.5 percentage points are due to the elevated separation rate, while staggering aggregate productivity contributes 0.9 percentage point. Moreover, the contribution of the UI benefit extensions to the elevated unemployment rate increases from 2009 to 2011; while the number of vacancies has been recovering, the unemployment rate has remained elevated because of the successive extensions. I also find that the December 2010 extension has moderately slowed down the recovery of the unemployment rate, keeping the rate 0.6 percentage point higher during 2011.

Three directions of future research are promising. First, the model in this paper can be extended to a general equilibrium model. The general equilibrium model in which the government must finance the UI benefits is suitable for answering the welfare effects of the UI benefit extensions. Second, such model can be used to study the optimal UI program. Although there are already numerous attempts to investigate the optimal UI program using a more stylized model, an analysis with a carefully calibrated structural model has an advantage, as the key to answering the question is to compare the relative importance of different effects. Finally, what is the optimal response of the UI policy to business cycles? Recently Landais et al. (2011) and Mitman and Rabinovich (2011) have come up with different answers to this important question. The business cycle version of the model developed in this paper, with rich features, can contribute to the discussion.

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Appendix to: A Quantitative Analysis of Unemployment Benefit Extensions

Makoto Nakajima*

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This appendix consists of three sections. Appendix A provides a detailed description of the unemployment insurance (UI) benefit extensions that have been implemented in the U.S. since the onset of the Great Recession. Appendix B gives a detailed description of the computational methods employed to solve the model numerically. Appendix C contains all of the results of the sensitivity analysis.

Appendix A Unemployment Insurance Benefit Extensions: Facts

Although standard UI benefits last 26 weeks in most states, the government often enacts extensions of UI benefits during economic downturns.[1] There are two types of extensions, both of which have been activated during the recent downturn. Remember that, under both types of extensions, the level of benefits is the same as the level of the regular benefits.

The first type of extension is called the extended benefits (EB) program. It is a permanent program that is automatically activated for a state whenever the unemployment rate of that state reaches a certain level.[2] The EB program provides an additional 13 or 20 weeks of UI benefits for most states if the unemployment rate of the state exceeds 6.5 percent or 8.0 percent, respectively. Currently, a majority of states qualify for the 20 weeks of extended UI benefits under the EB program. To give an idea of the approximate timing when the extended UI benefits under the EB program became available, let's use the national average unemployment rate. The national average unemployment rate exceeded the threshold for the 13 weeks of extended benefits under the EB program (6.5 percent) in November 2008. The national unemployment rate went above the threshold for 20 weeks of extended benefits under the EB program (8.0 percent) in March 2009. Since then, the national average unemployment rate has remained above the threshold for the 20-week UI benefit extension.

*Research Department, Federal Reserve Bank of Philadelphia. Ten Independence Mall, Philadelphia, PA 19106. E-mail: makoto.nakajima@phil.frb.org. Tel: +1-215-574-3905. The views expressed here are those of the author and do not necessarily reflect the views of the Federal Reserve Bank of Philadelphia or the Federal Reserve System.

[1] This appendix borrows heavily from the description of UI benefit extensions by Fujita (2010).

[2] To be more precise, the three-month average of the state unemployment rate is used.

Table 1: Recent Extensions of UI Benefits.[1]

Date	Description
June 30, 2008	The EUC08 program was introduced. The maximum duration of the additional benefits under the program was 13 weeks. It is called Tier 1 of extended UI benefits. The expiration date was set for March 28, 2009.
November 21, 2008	The maximum entitlement under Tier 1 was extended from 13 to 20 weeks. Tier 2, which provides a maximum of 13 weeks of additional UI benefits in states with an unemployment rate of at least 6 percent, was introduced. The expiration date remained at March 28, 2009.
February 17, 2009	As part of the American Economic Recovery and Reinvestment Act, the expiration date was pushed back to December 26, 2009. The act also included a provision to pay an additional weekly benefit of $25 to those receiving extended UI benefits under the EUC08.
November 6, 2009	The duration of additional UI benefits was substantially expanded. Tier 1 remained 20 weeks, but Tier 2 was expanded to 14 weeks and no longer depends on the state unemployment rate. A newly introduced Tier 3 provides an additional 13 weeks of benefits for those in states with an unemployment rate of at least 6 percent, and another newly introduced Tier 4 provides an additional six weeks for states with an unemployment rate higher than 8.5 percent. The expiration date was fixed at December 26, 2009.
December 19, 2009	The expiration date was pushed back to February 28, 2010, without changing the existing tier structure.
March 2, 2010	The expiration date was pushed back to March 31, 2010, without changing the existing tier structure.
April 15, 2010	The expiration date was pushed back to June 2, 2010, without changing the existing tier structure.
June 22, 2010	The expiration date was pushed back to November 30, 2010, without changing the existing tier structure.
December 17, 2010	The expiration date was pushed back to January 3, 2012 without changing the existing tier structure.

[1] Based on Fujita (2010), "The Chronology of the Emergency Unemployment Compensation Program (EUC08)."

The second type of extension is not automatic; Congress enacts this type of extension temporarily in response to severe downturns. The latest program in this category, the Emergency Unemployment Compensation program (EUC08), represents the eighth time Congress has created such a program.[3] EUC08 was signed into law in June 2008. Initially, the maximum duration of extended

[3] Congress has enacted temporary extensions of UI benefits in 1958, 1961, 1971, 1974, 1982, 1991, 2002, and

UI benefits under the program was 13 weeks, but it has been extended several times since then. As of January 2011, the EUC08 and subsequent expansions provided extended benefits for up to 53 weeks. Combining the extensions under EUC08 (53 weeks) with the regular benefits (26 weeks) and the EB (20 weeks), an unemployed worker is entitled to UI benefits for up to 99 weeks in total. See Table 1 for a summary of the original EUC08 and the subsequent expansions and extensions.

Typically, the additional UI benefits under the EB program can be used after an unemployed worker exhausts all the tiers under the EUC08. Therefore, I refer to the additional benefits under the EB program as Tier 5. Also, for ease of notation, I will refer to the regular UI benefits as Tier 0.

Let me make three remarks about the nature of the ongoing extensions implemented in response to the recent downturn. First, they are very generous compared with past extensions. For example, before the current extensions, the most generous ones in the past provided about 60 weeks of benefits compared with the current extensions of up to 99 weeks.

Second, the EUC08 was gradually expanded. It is not as if unemployed workers were eligible for 99 weeks of UI benefits from the time the EUC08 was first enacted. Instead, as of June 2008 when the EUC08 was introduced, the available extension was only 13 weeks of additional UI benefits. It took a year and a half from the time the first EUC08 was enacted until the maximum of 99 weeks of additional UI benefits became available. In the main experiment of the paper, I will take into account this gradual expansion of the ongoing extensions.

Third, although the number 99 is widely cited to describe the generosity of the ongoing extensions, not all unemployed workers actually enjoy the full 99 weeks of extended UI benefits. In order to understand how many weeks of extended UI benefits an unemployed worker is actually entitled to, one needs to understand the tier structure and the expiration date. The expiration date is the deadline for applying to an upper tier. For example, let's consider the extension enacted on June 22, 2010. The extension did not change the existing tier structure, but it pushed back the expiration date by 23 weeks to November 30, 2010. This means that an unemployed worker cannot move up from the tier he is in as of November 30, 2010. If he is receiving UI benefits under Tier 1 as of November 30, the end of Tier 1 is the end of the UI benefits for him. In other words, except for unemployed workers who are close to exhausting Tier 0 (regular) UI benefits of 26 weeks, the unemployed workers who were receiving Tier 0 benefits as of the implementation of the extension (June 22) can only go up to Tier 1, as they will never exhaust Tier 1 benefits by the expiration date. Those who just started receiving regular UI benefits actually will not qualify even for Tier 1 under the extension because they will not exhaust the 26-week regular benefit (Tier 0) by the expiration date, which is 23 weeks ahead of the day of the extensions. Considering that the extensions, except for the one in December 2010, pushed back the expiration date by 11.0 weeks on average and each tier adds on average 14.6 extra weeks of UI benefits, each extension, except for the one in December 2010, allows the majority of unemployed workers to move up just one tier from the one they are in at the time of each extension. Meanwhile, the extension that was enacted in December 2010 pushed back the expiration date by 55 weeks. This means that unemployed workers can go up by about three tiers from the one they are in at

2008 so far. See Whittaker (2008) for more details about past extensions.

the time of each extension.

Appendix B Computation

B.1 Steady-State Equilibrium

In the steady state, there is no UI benefit extension ($x = 0$ for all workers in all periods), and the separation rate λ_t and aggregate productivity z_t are constant at $\overline{\lambda}$ and $\overline{z}$, respectively. Computing a steady-state equilibrium amounts to finding value functions $W(0, h, u, a, k)$ and $F(h)$, optimal decision rules $g^k(0, h, u, a, k)$ and $g^s(0, h, u, a, k)$, time-invariant probability measure μ, and labor market tightness for each skill type $\{\theta^h\}$ that together satisfy the equilibrium conditions listed in Section 3.9. The detailed computational algorithm is as follows:

1. Set an initial guess of labor market tightness $\{\theta^{h,0}\}$.

2. Given $\{\theta^{h,0}\}$, the job-finding rate per search effort $\{f^h\}$ and the matching probability per vacancy $\{d^h\}$ can be computed.

3. Given $\{f^h\}$, solve for the optimal value function for the worker $W(0, h, u, a, k)$. This step includes the following sub-steps.

   (a) Set grid points on the space of $k \in [\underline{k}, \overline{k}]$ so that the value function for the worker and the optimal decision rules can be stored in a computer. $\underline{k}$ is given by the calibration. $\overline{k}$ is set such that it is never binding for the optimization problem of the worker.

   (b) Set the initial guess for the value $W^0(0, h, u, a, k)$.

   (c) Using $W^0(0, h, u, a, k)$ as the future value, update the value function using the Bellman equations (1) and (4) and obtain $W^1(0, h, u, a, k)$. In evaluating the future value function for k' not on one of the grid points, an interpolation is used. I use the shape-preserving spline interpolation.

   (d) Check convergence. If the distance between $W^0(0, h, u, a, k)$ and $W^1(0, h, u, a, k)$ is smaller than the predetermined tolerance level, move on to the next step. The optimal decision rules $g^k(0, h, u, a, k)$ and $g^s(0, h, u, a, k)$ obtained in this step are the ones associated with the optimal value function. Otherwise, replace $W^0(0, h, u, a, k)$ by $W^1(0, h, u, a, k)$ and go back to step 3 (c).

4. Given $\{d^h\}$, solve for the optimal value function for the firm $F(h)$. This step includes the following sub-steps.

   (a) Set the initial guess for the value $F^0(h)$.

   (b) Using $F^0(h)$ as the future value, update the value function using the Bellman equation (6) and obtain $F^1(h)$.

   (c) Check convergence. If the distance between $F^0(h)$ and $F^1(h)$ is smaller than the predetermined tolerance level, move on to the next step. Otherwise, replace $F^0(h)$ by $F^1(h)$ and go back to step 4 (b).

5. With the job-finding rate $\{f^h\}$ and the optimal decision rules $g^k(0,h,u,a,k)$ and $g^s(0,h,u,a,k)$ at hand, simulate the economy until the type distribution converges to its stationary distribution. This step includes the following sub-steps.

   (a) Discretize the space of asset holdings $k \in [\underline{k}, \overline{k}]$ so that the type distribution μ can be stored in a computer. Notice that the grids used to store μ can be (desirably) finer than the grids used to store the value function and the optimal decision rules. In case the grids used for μ are finer, use piecewise linear interpolation to evaluate the optimal decision rules over finer grids.

   (b) Set the initial guess for the type distribution μ^0.

   (c) Use the transition probabilities for exogenous state variables, optimal decision rules $g^k(0,h,u,a,k)$ and $g^s(0,h,u,a,k)$, and the job-finding rate $\{f^h\}$, update the type distribution and obtain μ^1. When the optimal decision $g^k(0,h,u,a,k)$ falls between two grid points, the measure is allocated proportionally to the adjacent two grid points.

   (d) Check convergence. If the distance between μ^0 and μ^1 is smaller than the predetermined tolerance level, move on to the next step. Otherwise, replace μ^0 by μ^1 and go back to step 5 (c).

6. Update labor market tightness and obtain $\{\theta^{h,1}\}$ using the free-entry condition (7), the stationary type distribution, and the optimal decision rules.

7. Check convergence. If the distance between $\{\theta^{h,0}\}$ and $\{\theta^{h,1}\}$ is smaller than the predetermined tolerance level, a steady-state equilibrium is obtained. Otherwise, update $\{\theta^{h,0}\}$ by taking a weighted average of $\{\theta^{h,0}\}$ and $\{\theta^{h,1}\}$ and go back to step 2.

The algorithm above is a general one, but thanks to the property of the model that the bargaining outcome depends only on aggregate productivity, there is no need for iterations for labor market tightness. Specifically, after computing the firm's value using equation (6), the free-entry condition (7) provides the equilibrium labor market tightness $\{\theta^h\}$. The last step is to solve for the optimal value function of workers, given the equilibrium $\{\theta^h\}$, which has already been obtained.

B.2 Equilibrium with Deterministic Transition

An equilibrium with transition between two steady states is solved, for example, in Conesa and Krueger (1999). The details of the computational algorithm are described in Ríos-Rull (1999). The model used in the current paper adds two novel features to existing models. First, there are multiple (indeed, nine) policy changes (listed in Table 1) instead of the typical assumption of one policy change. Second, each policy change is announced in advance. I also assume that the government has a perfect commitment technology; the announcements are credible.

It is further assumed that all policy changes are temporary, in the sense that the economy after a policy change asymptotically reverts to the initial steady state.[4] The value functions for workers and firms associated with the steady state are denoted as $W_\infty(0, h, u, a, k)$ and $F_\infty(h)$, respectively. As an approximation, it is assumed that the economy converges to the initial steady state in period T. For a good approximation, T has to be a large number. It is also assumed that the economy starts from the initial steady state, and the type distribution in the initial steady state is denoted by μ_0.

The economy starts from period 1, with the extension 0 (associated with no announced extension). Notice that, even without an extension announced, the time-varying separation rate and aggregate productivity are revealed, which makes the path of the economy start to diverge from its steady state. In general, it is possible to include a policy change in $j = 0$. If there are J policy changes (UI benefit extensions), $J + 1$ sequences of the labor market tightness ($j = 0, 1, 2, ..., J$) need to be solved. A sequence of the labor market tightness associated with the policy change (UI benefit extension) j is $\{\theta^h_{j,t}\}^T_{t=\tau_j}$. Notice that the history associated with the policy change j starts from τ_j, which is the period in which the new policy is announced. Also notice that the j-th UI benefit extension is characterized by $x' = \chi_{j,t}(x, u, a)$. The detailed computational algorithm is as follows:

1. Start from the extension $j = 0$.
2. Set a guess for the sequence of the labor market tightness associated with the policy change j, $\{\theta^{h,0}_{j,t}\}^T_{t=\tau_j}$.
3. Given a sequence $\{\theta^{h,0}_{j,t}\}^T_{t=\tau_j}$, a sequence of the job-finding rate $\{f^h_{j,t}\}^T_{t=\tau_j}$ and a sequence of the matching probability per vacancy $\{d^h_{j,t}\}^T_{t=\tau_j}$ can be computed.
4. Solve for the value function for the workers $W_{j,t}(x, h, u, a, k)$ for $t = \tau_j, \tau_j + 1, ..., T$. This step includes the following sub-steps.
   (a) Let's start from the last period ($t = T$). Since it is assumed that the economy converges to the initial steady state in period T, the value function in period $t + 1$ is known: $W_{j,t+1}(x, h, u, a, k) = W_\infty(x, h, u, a, k)$.
   (b) Using $W_{j,t+1}(x, h, u, a, k)$, the time-varying separation rate and aggregate productivity, the job-finding rate, and the UI benefit extension characterized by $\chi_{j,t}(x, u, a)$, update the value function using the Bellman equations (1) and (4) and obtain $W_{j,t}(x, h, u, a, k)$. The optimal decision rules $g^k_{j,t}(x, h, u, a, k)$ and $g^s_{j,t}(x, h, u, a, k)$ are obtained in the process.
   (c) Keep going back until period $t = \tau_j$.
5. Starting from period τ_j, simulate the economy until period T. This step includes the following sub-steps.

[4] This assumption can be easily relaxed. When a policy change has a permanent effect, the steady state associated with the permanent policy change must be computed in advance and used as the end point.

(a) Start from $t = \tau_j$. First of all, set the initial type distribution μ_{j,τ_j}. In the case where $j = 0$, it is the initial steady-state distribution μ_0 by assumption. In the case where $j > 0$, the initial steady state is obtained by the distribution associated with the policy $j - 1$, i.e., μ_{j-1,τ_j} adjusted by the UI benefit extension $\chi_{j,t}(x, u, a)$.[5]

(b) Update $\mu_{j,t}$ and obtain $\mu_{j,t+1}$, using the job-finding rate $\{f^h_{j,t}\}$, optimal decision rules $g^k_{j,t}(x, h, u, a, k)$ and $g^s_{j,t}(x, h, u, a, k)$, and stochastic processes for the exogenous state variables.

(c) Keep updating the distribution up to period T.

6. Update the sequence of labor market tightness and obtain $\{\theta^{h,1}_{j,t}\}^T_{t=\tau_j}$ using the free-entry condition (7), the sequence of type distribution $\{\mu_{j,t}\}^T_{t=\tau_j}$, and the optimal decision rules.

7. Check convergence by comparing the sequence of labor market tightness $\{\theta^{h,0}_{j,t}\}^T_{t=\tau_j}$ and $\{\theta^{h,1}_{j,t}\}^T_{t=\tau_j}$. If the distance between them is smaller than the predetermined tolerance level, an equilibrium associated with the policy change (UI benefit extensions) j is obtained. Go to the next step. Otherwise, update $\{\theta^{h,0}_{j,t}\}^T_{t=\tau_j}$ by taking a weighted average of $\{\theta^{h,0}_{j,t}\}^T_{t=\tau_j}$ and $\{\theta^{h,1}_{j,t}\}^T_{t=\tau_j}$ and go back to step 3.

8. If an equilibrium sequence of the labor market tightness for all $j = 0, 1, .., J$ is obtained, go to the next step. Otherwise, go back to step 2 for a new $j = j + 1$.

9. Once an equilibrium associated with all policy changes (all UI benefit extensions) is computed, the actual path of the economy can be obtained. The actual history of the economy is obtained by combining the periods $\{\tau_j, \tau_j + 1, ...\tau_{j+1} - 1\}$ for all $j = 0, 1, ..., J$, with $\tau_{J+1} = T + 1$.

Let me make two remarks. First, notice that the problem can be simplified in the same way as described for the algorithm to compute a steady-state equilibrium. Basically, there is no need for iterations for labor market tightness. In particular, one can solve for the firm's value function and the equilibrium labor market tightness ($\{\theta^h_{j,t}\}^T_{t=\tau_j}$ for $j = 0, 1, ..., J$) without solving the worker's problem. Once the equilibrium labor market tightness is obtained, the worker's value function and optimal decision rules can be solved. Second, it is straightforward to see that the equilibrium with a one-time policy change without prior announcement, which is used by Conesa and Krueger (1999) and many others, is a special case with $J = 0$, $\tau_0 = \widetilde{\tau}_0 = 1$ and the policy change implemented in period 1.

Appendix C Sensitivity Analysis

I explore the sensitivity of the main results, which is the effect of UI benefit extensions on the unemployment rate, regarding the variety of parameters. Table 2 summarizes the results. The first panel of Table 2 states the data and the baseline results. The second to fourth panels

[5] The extension changes the distribution, in particular of x, only when the extension is implemented without prior announcement.

Table 2: Sensitivity Analysis

Economy	Δ in unemployment duration[1]		Δ in the unemployment rate[2]			
	10% Δ in rep. rate	1 week Δ in UI duration	Total	UI benefit extensions	Separation rate	Aggregate productivity
Data	0.50-1.5	0.08-0.20	4.7			
Baseline[3]	0.50	0.13	4.8	1.4	2.5	0.9
$\phi = 2.03$	0.31	0.08	4.7	0.9	2.3	1.6
$\phi = 1.50$	0.37	0.10	4.8	1.1	2.3	1.4
$\phi = 0.50$	0.69	0.17	5.0	1.9	2.8	0.3
$\phi = 0.35$	0.82	0.20	5.4	2.4	3.1	0.0
$\sigma = 1$	0.33	0.10	4.9	1.0	2.5	1.4
$\alpha = 0.50$	0.52	0.13	4.8	1.3	3.3	0.1
$\rho = 0$	0.76	0.20	4.9	2.1	2.6	0.1
$\rho = 0.15$	0.54	0.15	4.8	1.6	2.5	0.7
$\underline{k} = 0$	0.66	0.16	5.0	1.7	2.4	0.9
$\underline{k} = -2000$	0.45	0.12	4.7	1.3	2.5	0.9
$\overline{\omega} = 0.95$	0.50	0.13	4.8	1.4	2.5	0.9
$\epsilon_w = 0$	0.50	0.13	4.9	1.4	2.5	1.0
$\epsilon_w = 0.9$	0.50	0.13	4.8	1.5	2.5	0.8

[1] Among the UI-eligible unemployed. Steady-state comparison.
[2] Change from December 2007 to the average of September 2009 - September 2011.
[3] The calibrated parameter values in the baseline model economy are: $\phi = 0.92$, $\sigma = 2$, $\rho = 0.3$, $\underline{k} = -1000$, $\overline{\omega} = 0.97$, and $\epsilon_w = 0.449$.

correspond to three sets of sensitivity results. The second panel is associated with the sensitivity with respect to the search elasticity parameter ϕ. Remember that, in the baseline calibration, $\phi = 0.92$ is obtained such that the responses of the average unemployment duration to changes in the amount and the duration of UI benefits in the calibrated model are within the range of available empirical estimates. In investigating the effects of ϕ, I fix ϕ to a variety of values and implement the same experiments as for the baseline model. Let's start from $\phi = 1.5$ (the second row in the second panel). $\phi = 1.5$, which means a lower elasticity of search intensity than in the baseline, corresponds to a weaker response of the model to changes in the UI benefit policy. The average duration of unemployment increases by 0.37 week in response to a 10-percentage-point increase in the replacement rate of UI benefits. This is lower than the lower bound of the available empirical estimates (0.50). The average unemployment duration increases by 0.10 week in response to a 1-week increase in the duration of UI benefits, compared to 0.13 week in the baseline experiment. Not surprisingly, the contribution of the UI benefit extensions to the unemployment rate is smaller than the baseline results, at 1.1 percentage points. I further lower the search elasticity (increase ϕ) so that the model's response to a 1-week increase in the duration of UI benefits is at the lower bound of the available empirical estimates (0.08). This procedure yields $\phi = 2.03$ (top of the second panel). The average unemployment duration increases by 0.31 week when the replacement rate of UI benefits is increased by 10 percentage points, which is further below the lower bound of the available empirical estimates (0.50). The contribution of the UI benefit extensions to the unemployment rate is further reduced, to 0.9 percentage point. Considering that the model's response to steady-state changes in the UI benefit policy is either at the lower bound or below, 0.9 percentage point provides the lower bound of the contribution of the UI benefit extensions to the unemployment rate implied by the model.

In the opposite case where ϕ is lower (search elasticity is higher) than in the baseline calibration, the response of the model to changes in the UI benefit policy is stronger. With $\phi = 0.5$ (third row in the second panel), the response of the average unemployment duration to a 10-percentage-point increase in the replacement rate is 0.69 week. The average duration of unemployment increases by 0.17 week in response to a 1-week increase in the duration of UI benefits. The current UI benefit extensions contribute to a 1.9-percentage-point increase in the unemployment rate, compared to 1.5 percentage points in the baseline experiment. If I further increase the search elasticity (lower ϕ) so that the model's response to a 1-week increase in the duration of UI benefits is at the upper bound of the available empirical estimates, $\phi = 0.35$ is obtained. With $\phi = 0.35$ (bottom of the second panel), the contribution of the UI benefit extensions to the unemployment rate is 2.4 percentage points. Notice that the model with $\phi = 0.35$ implies a larger increase in the unemployment rate than in the data even though the contribution from the average productivity is calibrated to be zero. Therefore, the 2.4-percentage-point increase in the unemployment rate can be considered the upper bound of the contribution of the UI benefit extensions implied by the model.

The third panel of Table 2 summarizes the sensitivity with respect to other parameters that change the steady state of the model. I fix the search intensity parameter ϕ at the baseline value of 0.92, recalibrate the model, and run the same experiments as in the baseline model. First, $\sigma = 1$, which implies log utility for consumption, makes the contribution of the UI extensions to the unemployment rate smaller (1.0 percentage point). Not surprisingly, it also implies that the response of the average unemployment duration of the model to a 10-percentage-point increase in the UI replacement rate is too small (0.33) compared with the data (0.5-1.5). It is easy to see that once ϕ is recalibrated as in the baseline model, the contribution of the UI benefits to the unemployment rate will be larger and close to the baseline model. This argument can be applied to all the sensitivity experiments in this group. In other words, the bounds of the main result obtained in the sensitivity analysis with respect to ϕ are to a large extent valid even if other parameter values are changed, as long as ϕ is recalibrated. Second, the curvature parameter for the matching function α is lowered to 0.5 from the baseline value of 0.72. As you can see, the contribution of the UI benefit extensions on the unemployment rate does not change significantly (1.3 percentage points), but the composition between the separation rate and aggregate productivity changes; while the rising separation rate contributes to a 2.5-percentage-point increase in the unemployment rate in the baseline experiment, the contribution is 3.3 percentage points with $\alpha = 0.5$. Next is the sensitivity analysis with respect to the non-monetary benefit of unemployment, ρ. It is reduced from the baseline value of $\rho = 0.3$ to 0.15 and 0 for sensitivity analysis. $\rho = 0.15$ is the intermediate value and corresponds to the calibration of Bils et al. (2011). $\rho = 0$ implies that the value of unemployment consists solely of the monetary value of UI benefits. However, remember that the bargaining outcome is not affected by the choice of ρ in this model. With $\rho = 0$, the contribution of the UI benefit extensions to the unemployment rate is higher than the baseline result (1.4 percentage points) at 2.1 percentage points. At the same time, the response of the average duration of unemployment to a 1-week increase in the UI benefit duration is 0.2, which is at the upper bound of the empirical estimates. This result is intuitive since a lower value of unemployment makes unemployed workers more desperate in their job search, especially as they remain unemployed for a long time or they are exhausting savings. $\rho = 0.15$ generates a slightly stronger result than the baseline. Next, I change the borrowing constraint from the baseline value of $\underline{k} = -1000$ to -2000 and 0. The contribution of the UI benefit extensions to the unemployment rate implied by the model is stronger (1.7 percentage points) when the borrowing limit is tighter ($\underline{k} = 0$), because the tight borrowing limit makes the unemployed more desperate to find a job in the initial steady state, and the UI benefit extensions make the unemployed less desperate more substantially than in the baseline. As expected, a less strict borrowing limit ($\underline{k} = -2000$) implies a weaker contribution from the UI benefit extensions to the unemployment rate (1.3 percentage points). Finally, I change the parameter controlling the bargaining outcome from the baseline value of $\overline{\omega} = 0.97$ to 0.95. This implies larger profits for matched firms. The main results are found to be insensitive to this change.

In the bottom panel of Table 2, I change the elasticity of the average wage with respect to changes in labor productivity from the baseline value of 0.449, which is estimated by Hagedorn and Manovskii (2008). This change does not affect the steady state of the model, but the path of the time-varying aggregate productivity needs to be recalibrated such that the equilibrium path of the unemployment rate generated by the model tracks the empirical unemployment rate. The first experiment is to set $\epsilon_w = 0$. Notice $\epsilon_w = 0$ means that the average wage is constant. This experiment is inspired by a recent paper by Shimer (2011), who shows that real wages were rigid in the recent downturn. It turns out that the main result of the paper – the contribution of the UI benefit extensions to the unemployment rate – is not very sensitive to the assumption of wage rigidity. Second, I set $\epsilon = 0.90$, which is twice as large as the baseline value. A high value of wage elasticity implies that the surplus of the firms, and thus the number of vacancy postings, moves less than in the baseline for the same change in aggregate productivity. In other words, the model has a weaker amplification mechanism, as in Shimer (2005). The contribution of the UI benefit extensions to the unemployment rate (1.5 percentage points) turns out to be similar to the baseline result of 1.4 percentage points. However, in order for the path of the unemployment rate to closely track its empirical counterpart, aggregate productivity has to drop by 7.3 percent instead of 1.1 percent, since the model lacks a strong amplification mechanism with flexible real wages.

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