A Quantitative Theory of Time-Consistent Unemployment Insurance

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Abstract

During recessions, the U.S. government substantially increases the duration of unemployment insurance (UI) benefits through multiple extensions. Benefit extensions increase UI coverage and lead to higher average consumption of unemployed workers, but the expectation of an extension may reduce unemployed worker's job search incentives and lead to higher future unemployment. We show that benefit extensions in recessions arise naturally when the government forgoes prior commitment and makes discretionary UI policies. We endogenize a time-consistent non-commitment UI policy in a stochastic equilibrium search model, and use the model to quantitatively evaluate the benefit extensions implemented during the Great Recession. Switching to the (Ramsey) commitment policy would reduce the unemployment by 2.9 percentage points with small welfare gains.

Keywords: Time-consistent policy, Unemployment insurance, Search and matching
JEL classifications: E61, J64, J65, H21

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1 Introduction

The U.S. government has extended unemployment insurance (UI) benefits in response to higher unemployment since the 1950s. During the Great Recession, benefit durations were extended up to 99 weeks. On the one hand, these policies provide insurance coverage to more unemployed workers, increasing their average consumption. On the other hand, UI can create moral hazard problems by reducing workers' incentives to find jobs. In fact, a big debate in the literature is whether benefit extensions worsened unemployment during the past recession due to adverse incentives (e.g. Nakajima 2012, Hagedorn et al. 2015, and Chodorow-Reich et al. 2019).

This paper argues that benefit extensions can arise endogenously from the government's problem. Two ingredients are key to this result. First, low productivity and low search efficiency imply a low efficiency cost of UI extension during recessions. Second, a lack of commitment by the government to future policies means the UI policy is discretionary and chosen without regard to its ex ante effects. We characterize these effects in a time-consistent (Markov-perfect) equilibrium of the government's problem over the business cycle. We show that quantitatively the UI extensions chosen endogenously by the government in the model match the extensions during the Great Recession well. Counterfactually, if the government implemented commitment policies during the Great Recession, unemployment would be lower and welfare would be slightly higher.

We analyze the government's choice of UI policies in a stochastic equilibrium search and matching model with rise-averse workers and endogenous search intensity. A classical time-inconsistency issue exists here: ex ante the government wants to promise less generous benefits to stimulate search and job creation; ex post it wants to give more generous benefits for insurance. This time-inconsistency means that the government's commitment to future policies matters. We use the Markov-perfect equilibrium to characterize the time-consistent UI policy that can be implemented without assuming the government's commitment. Specifically, each period a utilitarian welfare-maximizing government chooses the UI benefit level and duration — modeled using the probability that the benefit continues — as functions of current levels of unemployment and aggregate productivity.[1]

A key assumption is that once benefits expire, the unemployed worker does not regain eligibility before he finds a job. Under this assumption, benefit duration policy today, through changing the proportion of unemployed UI recipients, directly changes the measures of unemployment next period, and thus the future policies.

The private sector's decisions are modeled using a search-matching model with risk-

[1] Modeling the benefit duration using a probability rather than a fixed length keeps the government's problem tractable.

averse workers, endogenous search intensity by the unemployed, and business cycles driven by shocks to the aggregate productivity. Unemployed workers search for jobs, while firms post vacancies. Both parties make decisions given the government's policy choices. Future government policies affect worker's expected net value of employment, so the unemployed worker's search depends on the expectations about future government policies. More generous future benefit policies (higher benefit level or longer benefit duration) reduce the unemployed UI recipient's incentive to search. Because the duration policy directly changes the future states of the economy, it affects the worker's expectations about future policies. With endogenously determined wages, UI policy also affects firm's job posting through its effect on wages. The government's policy decision takes into account these effects of expectations.

The main trade-off associated with the government's duration policy is between insurance and incentives. A longer duration increases the UI coverage today and raises the average consumption of unemployed workers. It also reduces the average job search as it increases the share of unemployed UI recipients. And because UI recipients search less than non-recipients in the model, this change on the extensive margin raises future unemployment. In the equilibrium, workers expect longer future benefit duration when the unemployment is high. This expectation lowers search by the UI recipients, which also contributes to higher future unemployment.

In a recession, an initial drop in productivity reduces firm's job posting and lowers the response of unemployment to changes in search activity. This allows the government to extend benefits with lower efficiency costs. This effect is present for both the time-consistent policy and the Ramsey-style commitment policy. As the unemployment starts rising, the social values of individual search become larger as there are more people searching. In response, the governments use UI policy to increase search activity. The time-consistent UI duration is extended further as the government without commitment does not take into account that the expectation of longer UI extensions reduces search activities ex ante. This government is only forward-looking. A longer UI duration increases future unemployment, which in the equilibrium raises unemployed workers' current search. In contrast, because the Ramsey government takes into account the ex ante disincentive effects of UI extensions, it reduces (or extends less) UI duration when the unemployment is high. So overall, the Ramsey UI duration policy is less countercyclical than the time-consistent policy.

We apply the model to the U.S. economy between 2008 and 2013. Overall, the time-consistent policy generates 70% of the average benefit extension observed in the data. The substantial UI extensions contribute to higher unemployment in the equilibrium. In comparison, if the government is able to implement the optimal commitment (Ramsey) policy in the Great Recession, unemployment would be up to 2.9 percentage points lower between 2008 and 2013. This is mainly because in response to higher unemployment the government with commitment lowers the UI duration, which dampens the rise in unemployment. Alternatively, if the government commits to keeping the UI policy unchanged at its pre-recession level ("acyclical policy"), unemployment would be up to 1.2 percentage points lower. Switching from the time-consistent policy to a commitment policy in the Great Recession has positive and small welfare effects. Switching to the Ramsey policy would improve lifetime welfare by 0.12%, while switching to the acyclical policy would improve welfare by 0.011%.

It is worth noting that with endogenously determined wages, future UI policies have an effect on firm's current job posting (and vacancy–unemployment ratio) through the firm's expectation of future wages. This effect, similar to the effect of future UI policies on unemployed workers' job search, is also ex ante and is hence not taken into account by the government without commitment. The Ramsey government, in contrast, can use UI policy to lower wages and dampen the fall in firm's job posting during a recession. In an alternative setup where wages only respond to the underlying productivity, governments cannot use UI policies to affect wage levels. There, the Ramsey government loses the ability to boost job posting through wages, and we find that the Ramsey UI benefits are reduced less during the Great Recession. As a result, the difference in unemployment between the Ramsey and Markov economies is also smaller, compared to the baseline.

This paper is related to two strands of literature. First, it contributes to the literature on optimal UI policy. A long tradition of literature have studied the optimal design of UI policy where UI creates search disincentive (see, for example, Hopenhayn and Nicolini 1997; Wang and Williamson 2002; Shimer and Werning 2008; Chetty 2008; Golosov et al. 2013). A relatively new topic studies the optimal response of UI to business cycles (see, for example, Mitman and Rabinovich 2015; Jung and Kuester 2015; Landais et al. 2018; McKay and Reis 2017). The existing literature has assumed government commitment to future UI policies. We complement this literature by relaxing the commitment assumption and characterizing the time-consistent UI policy. Because the government does not need commitment to implement the time-consistent policy, the policy studied here is arguably a more realistic counterpart to policy-making in reality. We use the concept of Markov-perfect equilibrium, which delivers quantitatively relevant predictions, thus giving us a framework to address quantitative questions.

Most closely related to our work are Mitman and Rabinovich (2015) and Jung and Kuester (2015). Also using a standard search model they find that UI policies, absent other labor market instruments, should be less generous during recessions. We show that in the presence of time-inconsistency issues, the assumption about government commitment is the key for the different results. Landais et al. (2018) use a sufficient statistics approach to decompose the changing gains and costs of UI over unemployment, and find it optimal to have more generous UI when unemployment is higher. Our work also complements Birinci and See (2017) and Kekre (2017), who find that in a search framework with incomplete markets (the former) or aggregate demand externality (the latter), more generous UI policies (with commitment) in recessions can be welfare-improving.

Second, this paper is related to the vast literature on time-consistent policy. Time-consistent equilibrium has been widely used to study monetary policy and taxation (see, for example, Alesina and Tabellini 1990; Chari and Kehoe 2007; Song et al. 2012; Bianchi and Mendoza 2018). We apply the concept to UI policy. Following Klein, Krusell, and Ríos-Rull (2008), we use the Generalized Euler Equations to characterize the government's choices and compare to the Ramsey commitment policy.

The rest of the paper proceeds as follows. Section 2 describes the model environment and defines the private-sector equilibrium. Section 3 defines the Markov-perfect time-consistent equilibrium. We characterize the time-consistent UI policy and compare it to the Ramsey commitment policy to provide some intuitions. Section 4 describes the parametrization strategy. Section 5 presents the quantitative equilibrium results. Section 6 focuses on UI extensions during the Great Recession. Section 7 concludes.

2 Model

In this section, we describe the model environment and characterize the equilibrium in the private sector given government policy. The model is based on a search-matching framework with aggregate productivity shocks.

2.1 Model environment

Time is discrete and infinite. The labor market in this model is populated by a continuum of workers and firms. The measure of workers is normalized to one. In any given period, a worker can be either employed or unemployed. Some unemployed workers receive UI benefits. Workers are risk averse and maximize expected lifetime utility given by

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(c_t, s_t), \quad U(c_t, s_t) = \log(c_t) - v(s_t),$$

where $\mathbb{E}_0$ is the period 0 expectation operator, and β is the time discount factor. Period utility $U(\cdot, \cdot)$ comprises of utility from consumption $\log(c)$ and disutility from job search $v(s)$, where v is a non-negative, strictly increasing, and convex function. Utility is increasing in c and decreasing in s. The concavity introduced by a log function allows us to study the insurance motive of the government. Only unemployed workers choose positive search intensity; that is, there is no on-the-job search. Each period, an employed worker is paid wages from production. Wage determination is specified later in this section. All unemployed workers derive utility from nonmarket activity h. In addition, an unemployed worker on unemployment benefits ("UI recipient") receives UI benefits b each period. There is no private insurance market and workers cannot save or borrow. A worker's consumption is his income (wage, or home production with or without UI benefits) net of taxes.

Firms are risk neutral and maximize the expected discounted sum of profits, with the same discount factor β as workers. A firm produces output if it hires a worker. In order to hire, the firm posts a vacancy by paying a flow cost κ.

Unemployed workers and vacancies form new matches according to the matching function $M(I,V)$ where I is the aggregate search and V is aggregate vacancies. The job-finding probability per efficiency unit of search ("search efficiency"), f, and the job-filling probability per vacancy, q, are functions of the labor market tightness, $\theta = V/I$: $f(\theta) = M(I,V)/I = M(1,\theta)$ and $q(\theta) = M(I,V)/V = M\left(\frac{1}{\theta},1\right)$. Existing matches are destroyed exogenously with job separation probability δ.

Each period, a matched pair of worker and firm produces z, where z is the aggregate productivity that follows a persistent exogenous process and is equal to $\bar{z}$ at the steady state.

2.2 Government policy

The government cannot borrow or save; instead, it balances the budget each period. The government finances the UI system through a lump sum tax, τ, on all workers, both employed and unemployed. The government budget constraint is

$$\tau = u_{benefit} b, \tag{1}$$

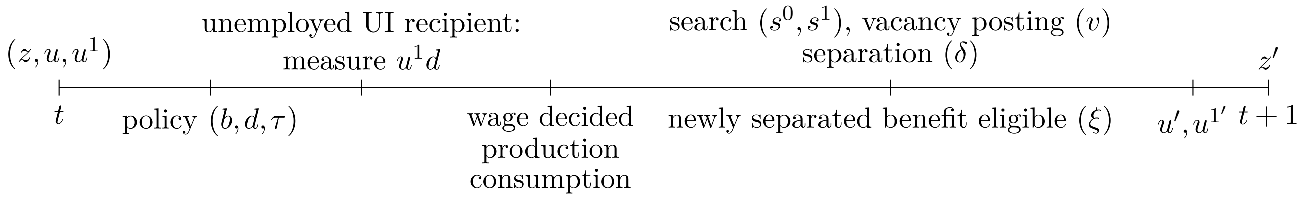
where $u_{benefit}$ is the measure of UI recipients.

The UI program has two policy instruments: (1) the benefit level, $b > 0$, and (2) the benefit duration probability $d \in (0,1)$, where with probability d an unemployed worker eligible for benefits receives benefits today, and $1/(1-d)$ is the potential benefit duration. A higher d increases the measure of UI recipients $u_{benefit}$, everything else equal.

We assume a period-by-period balanced government budget in the baseline model. While it may not be the case especially during recessions, it is done to make the non-commitment problem more tractable. If the government is allowed to run deficits during recessions, it will have more fiscal capacity to make benefits more generous in recessions. We consider the implications of relaxing the balanced budget constraint in Section 6.2 as an alternative to the baseline setup.

2.3 Timing

The timing of events within a period is illustrated below.



The economy enters period t with a measure of the total unemployed workers u and a measure of the *benefit-eligible* unemployed workers u^1. The aggregate shock z then realizes. (z, u, u^1) are the aggregate states of the economy.

Once government policies (b, d, τ) for the period are announced, $u_{benefit} = u^1 d$ workers collect benefits (UI recipients). In other words, with probability $1 - d$, benefit-eligible unemployed workers lose benefit status in this period and will not be eligible until they find a job, which is consistent with how UI policy normally works. Employed workers produce z and receive wages w. Everyone consumes income net of lump-sum tax τ. Finally, labor market turnovers take place as follows.

Given aggregate states and government policies for the period, unemployed workers choose how much to search: s^1 and s^0 for UI recipients and non-recipients, respectively. Firms post vacancies at cost κ. A fraction δ of the existing $1 - u$ matches are exogenously destroyed. With probability ξ newly unemployed workers become benefit eligible for the next period.[2] The unemployment states of the next period $u', u^{1'}$ are determined, and in particular, benefit-eligible newly unemployed workers and UI recipients still unemployed at the end of the period make up next period's benefit-eligible unemployment $u^{1'}$. Because those who lose UI status do not regain eligibility before they find a job, the duration policy d directly affects $u^{1'}$. The matches formed today do not start producing until the next period.

Given the search efficiency $f(\theta)$, the laws of motion of unemployed workers are given by

$$\text{total unemployment:} \quad u' = \underbrace{\delta(1-u)}_{\text{newly unemployed}} + \underbrace{(1 - f(\theta)s^0)(u - u^1 d) + (1 - f(\theta)s^1)u^1 d}_{\text{previously unemployed who do not find job}}, \tag{2}$$

$$\text{benefit-eligible unemployed:} \quad u^{1'} = \underbrace{\delta(1-u)\xi}_{\text{benefit-eligible newly unemployed}} + \underbrace{(1 - f(\theta)s^1)u^1 d}_{\text{UI recipients who do not find job}}. \tag{3}$$

This timing highlights the time-inconsistency issue of UI policy. Search and job posting today determine unemployment at the end of today. Before search and job posting take place, the government would like to promise less generous future UI benefits to encourage job creation and lower unemployment (ex ante incentive), but after unemployment is determined, the government wants to implement generous policies for insurance purposes (ex post incentive).

[2] In reality, not all newly unemployed workers qualify for benefits. And among those who qualify a fraction choose not to collect. Following the literature on unemployment insurance (e.g. Zhang and Faig 2012, Nakajima 2012), we model it using a probability for simplicity here.

This time-inconsistency makes the government's commitment to *future* policies relevant.[3]

Importantly, because consumption takes place before search, today's search does not affect today's consumption. As such, changes in current benefit level b do not have a direct effect on search today. But because search today affects employment status and hence consumption tomorrow, the (anticipated) future benefit level b' does affect search today.

Notation: Let $\mathcal{O}$ denote aggregate states (z, u, u^1) and g denote government policy (b, d, τ).

2.4 Workers' value functions

A UI recipient consumes $h + b - \tau$ and chooses search intensity s^1; a non-recipient consumes $h - \tau$ and his search intensity is s^0. With probability $f(\theta)s,\ s \in \{s^0, s^1\}$, the unemployed worker finds a job and starts working the following period. Let $V^e(\mathcal{O}; g)$, $V^1(\mathcal{O}; g)$ and $V^0(\mathcal{O}; g)$ be the value of an employed worker, an unemployed UI recipient and non-recipient, respectively, given the aggregate states and government policy for the period.

The problem of an unemployed non-recipient (superscript 0 denotes no benefits) is

$$V^0(\mathcal{O}; g) = \max_{s^0} \log(h - \tau) - v(s^0) + f(\theta)s^0 \beta \mathbb{E} V^e(\mathcal{O}'; g') + (1 - f(\theta)s^0)\beta \mathbb{E} V^0(\mathcal{O}'; g'), \quad (4)$$

and the problem of a UI recipient is

$$\begin{aligned} V^1(\mathcal{O}; g) &= \max_{s^1} \log(h + b - \tau) - v(s^1) + f(\theta)s^1 \beta \mathbb{E} V^e(\mathcal{O}'; g') \\ &\quad + (1 - f(\theta)s^1)\beta \mathbb{E}\Big[(1 - d')V^0(\mathcal{O}'; g') + d'V^1(\mathcal{O}'; g')\Big]. \end{aligned} \quad (5)$$

UI duration policy tomorrow d' affects the continuation value of the UI recipient: if he is still unemployed at the end of the period, with probability d' he keeps benefits next period.

A worker entering a period employed produces and consumes $w - \tau$. With probability δ, he loses his job and becomes unemployed. A newly unemployed worker is benefit eligible next period with probability ξ. The Bellman equation of an employed worker is then

$$\begin{aligned} V^e(\mathcal{O}; g) &= \log(w - \tau) + (1 - \delta)\beta \mathbb{E} V^e(\mathcal{O}'; g') \\ &\quad + \underbrace{\delta(1 - \xi)\beta \mathbb{E} V^0(\mathcal{O}'; g')}_{\text{benefit ineligible newly unemployed}} + \underbrace{\delta\xi\beta \mathbb{E}\Big[(1 - d')V^0(\mathcal{O}'; g') + d'V^1(\mathcal{O}'; g')\Big]}_{\text{benefit eligible newly unemployed}}. \end{aligned} \quad (6)$$

Notation: To avoid unnecessarily long equations we use U^e, U^1 and U^0 to denote the workers' period utilities: $U^e = \log(w - \tau)$, $U^1 = \log(h + b - \tau) - v(s^1)$, and $U^0 = \log(h - \tau) - v(s^0)$.

[3] If search and job posting happen before consumption within the period, then search depends directly on the same-period UI policy, which is made before search takes place. In that case, there is no direct time-inconsistency of the UI policy, although there is still time-inconsistency through the inter-temporal *search-smoothing* incentive of the unemployed workers. The online Appendix D3 explains the timing difference.

2.5 Firm's value function

A vacant firm posts a vacancy at flow cost κ. With probability $q(\theta)$, a vacancy is filled and starts production the following period. Let $J^u(\mathcal{O};g)$ and $J^e(\mathcal{O};g)$ be the values of a vacant and a matched firm, respectively. A matched firm receives output net of wages $z-w$. With probability δ, a match is destroyed at the end of the period and the firm becomes vacant. The Bellman equation of a matched firm is

$$J^e(\mathcal{O};g) \quad = \quad z - w + (1-\delta)\beta\mathbb{E}J^e(\mathcal{O}';g') + \delta\beta\mathbb{E}J^u(\mathcal{O}';g'), \tag{7}$$

and the Bellman equation of a vacant firm is

$$J^u(\mathcal{O};g) \quad = \quad -\kappa + q(\theta)\beta\mathbb{E}J^e(\mathcal{O}';g') + (1-q(\theta))\beta\mathbb{E}J^u(\mathcal{O}';g'). \tag{8}$$

In the equilibrium and under free entry condition, a firm posts vacancies until $J^u(\mathcal{O};g) = 0$, which requires the total expected value of profits be equal to the flow cost of posting vacancy:

$$\frac{\kappa}{q(\theta)} = \beta\mathbb{E}J^e(\mathcal{O}';g'). \tag{9}$$

2.6 Wage determination

As is customary in the literature, we assume wages are determined through Nash bargaining, which allows UI policies to affect wages endogenously. There is an active debate on whether and how much UI affects wages, yielding a wide range of estimates. It is not the purpose of this paper to settle this debate. Rather, we explore how wage mechanisms affect government policy. As the baseline, we assume the worker's outside option is unemployment *without* UI:

$$\max_{w} \quad (J^e - J^u)^{1-\zeta}\left(V^e - V^0\right)^{\zeta}, \tag{10}$$

where ζ is the worker's bargaining power. This is consistent with the policy in the U.S. where a worker who quits from a job does not receive UI benefits. UI benefit level and duration affect wages only through taxes in this specification: more generous benefits lead to higher taxes, which raise the worker's marginal utility to consume and increase wages by strengthening the worker's bargaining position.[4]

As an alternative, we use an exogenous wage rule similar to Landais et al. (2018) and McKay and Reis (2017):

$$w(z) = \bar{w}z^{\epsilon_w}, \quad \epsilon_w \in [0,1). \tag{11}$$

[4] We thank the referee for the suggestion to explore the effects of the wage mechanism on UI policies. A more general bargaining rule is $\max_w (J^e - J^u)^{1-\zeta}\left(V^e - \psi V^1 - (1-\psi)V^0\right)^{\zeta}$. It allows workers some probability (ψ) of getting UI benefits when bargaining breaks down. Then a higher UI benefit additionally raises wages by increasing the worker's outside value V^1. The Markov equilibrium that we specify later only allows small ψ values, as otherwise b would explode and there is no (empirically-relevant) steady state. We show this both theoretically and numerically in the online Appendix D2, which also includes quantitative results using small ψ values and shows the main properties of the Markov equilibrium still hold.

This wage rule shuts down the effects of UI policies on wages. Section 6.2 discusses the implications of exogenous wages. The full results are included in the online Appendix D1.

2.7 Equilibrium in the private sector

The equilibrium in the private sector given government's policy is defined as follows.

DEFINITION 1. (Private-sector equilibrium) Given UI policy $g = (b, d, \tau)$ and initial states $\mathcal{O} = (z, u, u^1)$, an equilibrium consists of $\mathcal{O}$-measurable functions for worker's search intensities $s^0(\mathcal{O}; g)$ and $s^1(\mathcal{O}; g)$, market tightness $\theta(\mathcal{O}; g)$, wages $w(\mathcal{O}; g)$, total unemployment $u'(\mathcal{O}; g)$ and benefit-eligible unemployment $u^{1'}(\mathcal{O}; g)$, and value functions $V^e(\mathcal{O}; g)$, $V^0(\mathcal{O}; g)$, $V^1(\mathcal{O}; g)$, $J^e(\mathcal{O}; g)$ and $J^u(\mathcal{O}; g)$, such that for all $(\mathcal{O}; g)$:

- the value functions satisfy the worker's and firm's Bellman equations (4)-(8);
- the search intensities s^0 and s^1 solve the unemployed worker's maximization problems of (4) and (5), respectively;
- the market tightness θ is consistent with the free-entry condition (9);
- the wages w solve the maximization problem of (10);
- the measures of unemployment satisfy the laws of motion (2)-(3).

2.8 Characterization of private-sector optimality

The private-sector equilibrium can be characterized by four optimality conditions.[5] In what follows, primes denote variables of the following period, and subscripts denote derivatives.

Worker's search incentive. The search choices s^0 and s^1 are characterized respectively by

$$\text{non-UI recipients:} \quad \frac{v_s(s^0)}{f(\theta)} = \beta \mathbb{E}\left\{ U^{e'} - U^{0'} + [1 - f(\theta')s^{0'} - \delta(1-\xi)] \frac{v_s(s^{0'})}{f(\theta')} - \delta\xi \frac{v_s(s^{1'})}{f(\theta')} \right\}, \tag{12}$$

$$\begin{aligned} \text{UI recipients:} \quad \frac{v_s(s^1)}{f(\theta)} &= \beta \mathbb{E}(1-d')\left\{ U^{e'} - U^{0'} + [1 - f(\theta')s^{0'} - \delta(1-\xi)] \frac{v_s(s^{0'})}{f(\theta')} - \delta\xi \frac{v_s(s^{1'})}{f(\theta')} \right\} \\ &+ \beta \mathbb{E} d' \left\{ U^{e'} - U^{1'} + [1 - f(\theta')s^{1'} - \delta\xi] \frac{v_s(s^{1'})}{f(\theta')} - \delta(1-\xi) \frac{v_s(s^{0'})}{f(\theta')} \right\}. \end{aligned} \tag{13}$$

The worker's optimality conditions state that the marginal cost (left-hand side) of higher search intensity equals the marginal value (right-hand side). The marginal cost is the marginal disutility from search weighted by the aggregate search efficiency. The marginal value is the expected value of the utility gain from employment next period *and* the benefit of economizing on future search cost. As such, the conditions capture unemployed workers' *search-smoothing* incentive. We can make two useful observations.

[5] To economize on notation, we suppress the dependence on aggregate states and government policy $(\mathcal{O}; g)$. It should be understood throughout that the equilibrium allocations are functions with arguments $(\mathcal{O}; g)$. The online Appendix C1 contains the derivation of the optimality conditions.

Proposition 1. Unemployed UI recipients search less than non-recipients, $s^1 < s^0$, given $v_s(s) > 0$ and $v_{ss}(s) > 0$, $b' > 0$ and $0 < d' < 1$.

The UI recipient's marginal value of search (right-hand side of Equation 13) depends on the future UI duration policy d'. Because the first part is identical to the marginal gain of the non-recipients (Equation 12) and is larger than the second part (as $b' > 0$ is inside $U^{1'}$), the marginal value of search is lower for the UI recipients, as long as the future duration probability (d') is strictly greater than 0. Given an increasing marginal search cost function, it then implies that the UI recipients search less. In other words, a non-zero probability of receiving benefits *tomorrow* creates a moral hazard problem today for the UI recipients.

Proposition 2. A higher future UI duration (larger d') or a higher future benefit b' reduces the search incentive of the UI recipients.

A larger d' reduces the marginal value of search (right-hand side of Equation 13) and hence the search incentive of UI recipients. At the same time, the marginal value is also decreasing in b' (inside $U^{1'}$), so the search incentive is lower when the future benefit is expected to be higher.

Firm's vacancy posting incentive. From the firm's free entry condition we get the optimality condition characterizing the labor market tightness:

$$\frac{\kappa}{q(\theta)} \;=\; \beta\mathbb{E}\left[z' - w' + (1-\delta)\frac{\kappa}{q(\theta')}\right]. \tag{14}$$

The marginal cost (left-hand side) equals the marginal value (right-hand side) of a filled vacancy. The marginal cost is the flow cost of posting a vacancy weighted by the probability of filling that vacancy. The marginal value is the expected future profit and continuation value of the match. Because a newly formed match does not become operational until the next period, the value of a match only depends on the expected *future* values.

The firm's vacancy posting incentive is lower when the expected future productivity z' is smaller or future wages w' are higher. The current productivity z does not directly impact the firm's current hiring decision. Instead, due to persistence in the productivity process it affects the firm's expectation of future productivity and hence its current hiring decision. Future UI policy also affects firm's vacancy posting through its effects on future wages w'.

Nash bargaining. The Nash bargaining rule (10) implies that the equilibrium wages are determined according to:

$$\zeta(J^e - J^u) \;=\; (1-\zeta)(V^e - V^0)/U_c(w-\tau), \tag{15}$$

where the worker's surplus is

$$V^e - V^0 \;\equiv\; (1-\zeta)\left\{U^e - U^0 + [1 - f(\theta)s^0 - \delta(1-\xi)]\frac{v_s(s^0)}{f(\theta)} - \delta\xi\frac{v_s(s^1)}{f(\theta)}\right\}. \tag{16}$$

More generous UI benefits raise taxes and the worker's marginal utility to consume on the right-hand side of Equation (15), which leads to higher bargained wages. In addition, more generous *future* benefits indirectly decrease current wages, as higher future benefits lower s^1, which increases worker's surplus $V^e - V^0$.

3 Time-Consistent Equilibrium

The government maximizes the expected value of workers' utility using policy tools, which include benefit level b, benefit duration probability d, and lump-sum tax τ.

A potential time-inconsistency issue exists as described before. Because of this time-inconsistency, policies such as the Ramsey policy require government commitment to future policies, as otherwise the policy cannot be implemented by the government. We take a different approach and instead consider the time-consistent equilibrium policies that can be implemented by a government without commitment. We follow Klein et al. (2008) and focus on the Markov-perfect equilibrium policy that depends differentiably on the payoff-relevant aggregate states — (z, u, u^1) in our case.

The timing of events is as outlined in Section 2.3. Because each worker or firm is infinitely small, they take government policies as given. We express the lump-sum tax as a function of other policies using the government's budget constraint:

$$\tau = u^1 db. \tag{17}$$

The *period-welfare function* is equal to the average utility of all workers, given by

$$R(z, u, u^1, b, d, s^0, s^1, w) = (1-u)U^e + u^1 dU^1 + (u - u^1 d)U^0, \tag{18}$$

where U^e, U^0 and U^1 again denote the workers' period utilities.

A few redistributional (*insurance*) effects are obvious from the tax and period-welfare functions. For example, an increase in the total unemployment (u) reduces the average utility by reducing the proportion of employed workers, ceteris paribus. A benefit extension (an increase in d) raises the average utility by increasing the proportion of UI recipients among unemployed workers; it raises taxes and shifts consumption from workers and non-recipients to UI recipients.

The government chooses policies to maximize current and discounted future welfare, subject to the government budget constraint and the optimality conditions in the private sector. These optimality conditions capture the *incentive* effects of the policies.

Definition 2. (Markov-perfect equilibrium) A Markov-perfect equilibrium consists of government's value function G and policy rules Ψ^b and Ψ^d, and private decision rules $\left\{S^0, S^1, \Theta, W, \Gamma, \Gamma^1\right\}$ such that for all aggregate states $\mathcal{O} \equiv (z, u, u^1)$, the policies $b = \Psi^b(\mathcal{O})$, $d = \Psi^d(\mathcal{O})$,

$s^0 = S^0(\mathcal{O})$, $s^1 = S^1(\mathcal{O})$, $\theta = \Theta(\mathcal{O})$, $w = W(\mathcal{O})$, $u' = \Gamma(\mathcal{O})$, and $u^{1'} = \Gamma^1(\mathcal{O})$ solve

$$\max_{b,d,s^0,s^1\theta,w,u',u^{1'}} \quad R(\mathcal{O},b,d,s^0,s^1,w) + \beta\mathbb{E}G(\mathcal{O}')$$

subject to

- the worker's laws of motion (2) and (3);
- the private-sector optimality conditions (12), (13), (14), and (15);
- the government's budget constraint (17);
- the government value function satisfies the functional equation

$$G(\mathcal{O}) \equiv R(\mathcal{O},\Psi^b(\mathcal{O}),\Psi^d(\mathcal{O}),S^0(\mathcal{O}),S^1(\mathcal{O}),W(\mathcal{O})) + \beta\mathbb{E}G(z',\Gamma(\mathcal{O}),\Gamma^1(\mathcal{O})).$$

In the equilibrium, both the government's and the private sector's problems are solved with a rational expectation on future policy rules, and all successive governments follow the same set of policy rules.

3.1 Generalized Euler Equation: Unpacking the government's problem

For a better understanding of the government's choices of UI policies, we follow Klein et al. (2008) to look at the government's Generalized Euler Equations (GEEs). For expositional convenience, we use $MV(s^0;\mathcal{O}')$, $MV(s^1;\mathcal{O}')$, and $MV(\theta;\mathcal{O}')$ to denote the *private* marginal values of search and vacancy posting, which are the right-hand sides of the unemployed workers' and firm's Euler equations (12)-(14), respectively. Lagrange multipliers on these Euler equations $\mu_0, \mu_1, \gamma > 0$ represent the marginal social values of search and job posting.

Given the aggregate states, the duration probability d can be characterized by [6]

$$\begin{aligned} 0 \;=\; & \underbrace{u^1(U^1 - U^0)}_{\text{insurance effect}>0} + \underbrace{\frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial d}}_{\text{tax effect}<0} + \underbrace{\lambda\frac{\partial u'}{\partial d}}_{\text{extensive margin search effect}<0} + \underbrace{(1-u)U_c^e \left.\frac{\partial w}{\partial d}\right|_{\text{Nash}}}_{\text{wage bargaining effect}>0} \\ & + \underbrace{\frac{\partial u^{1'}}{\partial d}}_{>0}\Bigg[\underbrace{\left(\mu_0 \frac{\mathbf{d}MV(s^0;\mathcal{O}')}{\mathbf{d}u^{1'}} + \mu_1 \frac{\mathbf{d}MV(s^1;\mathcal{O}')}{\mathbf{d}u^{1'}} + \gamma \frac{\mathbf{d}MV(\theta;\mathcal{O}')}{\mathbf{d}u^{1'}}\right)}_{\text{higher } u^{1'} \text{ on private choices today}} + \beta\mathbb{E}\underbrace{\left(\frac{\partial R'}{\partial u^{1'}} + \lambda'\frac{\partial u''}{\partial u^{1'}} + (1-u')U_c^{e'} \left.\frac{\partial w'}{\partial u^{1'}}\right|_{\text{Nash}}\right)}_{\text{higher } u^{1'} \text{ on tomorrow's welfare}}\Bigg] \\ & + \beta\mathbb{E}\underbrace{\frac{\partial u^{1'}}{\partial d}}_{>0}\underbrace{\left.\frac{\partial d'}{\partial u^{1'}}\right|_{\text{hold } u^{1''} \text{ constant}}}_{<0}\Bigg[\underbrace{u^{1'}(U^{1'} - U^{0'}) + \frac{\partial R'}{\partial \tau'}\frac{\partial \tau'}{\partial d'} + \lambda'\frac{\partial u''}{\partial d'} + (1-u')U_c^{e'} \left.\frac{\partial w'}{\partial d'}\right|_{\text{Nash}}}_{\text{insurance, tax, extensive margin search and bargaining effects tomorrow}}\Bigg], \end{aligned} \tag{19}$$

[6] The online Appendix C2 contains the derivation of GEEs. Primes are used to denote future variables, e.g. u' for total unemployment tomorrow and $U^{e'}$ for the period utility of employed workers tomorrow. Subscripts denote partial derivatives, e.g. $U_c^e = U_c(w-\tau)$. $\mathbf{d}MV(x;\mathcal{O}')/\mathbf{d}u^{1'}$ is the total derivative of the marginal value of x with respect to $u^{1'}$ and contains policy derivatives.

where $\lambda < 0$ is the shadow value of unemployment and is given by

$$\begin{aligned}\lambda \;=\; & \left(\mu_0 \frac{\mathbf{d}MV(s^0;\mathcal{O}')}{\mathbf{d}u'} + \mu_1 \frac{\mathbf{d}MV(s^1;\mathcal{O}')}{\mathbf{d}u'} + \gamma \frac{\mathbf{d}MV(\theta;\mathcal{O}')}{\mathbf{d}u'}\right) + \beta\mathbb{E}\left(\frac{\partial R'}{\partial u'} + \lambda' \frac{\partial u''}{\partial u'}\right) \\ & + \beta\mathbb{E}\left.\frac{\partial d'}{\partial u'}\right|_{u^{1''}\text{constant}} \left[u^{1'}\left(U^{1'} - U^{0'}\right) + \frac{\partial R'}{\partial \tau'}\frac{\partial \tau'}{\partial d'} + \lambda' \frac{\partial u''}{\partial d'} + (1-u')U_c^{e'} \left.\frac{\partial w'}{\partial d'}\right|_{\text{Nash}}\right], \end{aligned} \tag{20}$$

and the benefit level b is characterized by

$$\underbrace{u^1 dU_c^1 + \frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial b}}_{\text{redistribution effect}} + \underbrace{(1-u)U_c^e \left.\frac{\partial w}{\partial b}\right|_{\text{Nash}}}_{\text{wage bargaining effect} > 0} = 0. \tag{21}$$

These equations summarize the marginal effects of a policy change in the Markov equilibrium. Equation (19) shows that a **benefit extension** (an increase in d) has the following effects.

First, a benefit extension increases the share of unemployed workers who are UI recipients today. This raises the average utility of workers today as UI recipients have higher utility than non-recipients (first term of 19). This is the *insurance* effect. This increased duration is financed through higher taxes, which create a negative *tax* effect on today's welfare (second term). Second, by increasing the share of UI recipients a benefit extension lowers average search, because UI recipients search less than non-recipients (Proposition 1). This leads to higher future unemployment, which has a marginal social value $\lambda < 0$. This is the *extensive margin search* effect (third term: $\partial u'/\partial d = u^1 f(\theta)(s^0 - s^1)$). Lastly, the *wage bargaining* effect through the Nash condition (15) is positive ($\partial w/\partial d > 0$), meaning an extension leads to higher wages. This wage effect is absent when wages are exogenous.

The second line of Equation (19) contains the effects of a benefit extension through raising the benefit-eligible unemployment $u^{1'}$ ($\partial u^{1'}/\partial d > 0$). The anticipation of higher future unemployment alters private choices today. For example, $\mathbf{d}MV(s^1;\mathcal{O}')/\mathbf{d}u^{1'}$ is the effect of higher $u^{1'}$ on the UI recipients' marginal value of search. Because $u^{1'}$ is a state tomorrow (in $\mathcal{O}'$), a change induces expected changes in tomorrow's UI policy and private choices, which in turn change the marginal value of search and the unemployed worker's search effort today. This is the *intensive margin search* effect. A positive value (as is the case quantitatively) means higher $u^{1'}$ increases the marginal value of today's search s^1, which has a social value μ_1. In addition to changing private choices, higher $u^{1'}$ has direct welfare costs: on tomorrow's average utility ($\partial R'/\partial u^{1'}$) and future unemployment ($\partial u''/\partial u^{1'}$).

The third line of Equation (19) contains the effects of an extension today on future welfare through changing tomorrow's duration. Holding $u^{1''}$ (eligible unemployment at the end of tomorrow) constant, an extension today reduces tomorrow's duration.[7] This shorter future duration then affects tomorrow's average utility and unemployment in similar ways as today.

[7] Note that holding $u^{1''}$ constant gives a partial equilibrium effect, which is less than 1 in absolute value. In the full Markov equilibrium, benefit extension today increases $u^{1'}$ which raises benefit duration tomorrow.

Equation (20) gives the expression for the marginal social value of unemployment u'. This is negative ($\lambda < 0$), implying that higher unemployment creates a negative net value on total welfare. Unemployment affects total welfare through its effects on private choices: for example, a positive $\mathbf{d}MV(s^1;\mathcal{O}')/\mathbf{d}u'$ means a higher unemployment increases the UI recipients' marginal value of search. Quantitatively, in the equilibrium, this is indeed the case. At the same time, higher u' leads to lower future average utility ($\partial R'/\partial u' = U^{0'} - U^{e'} < 0$) and higher future unemployment ($\partial u''/\partial u' > 0$). Lastly, because u' is a state tomorrow, a higher u' changes future UI duration policy, which impacts future welfare (second line).

During recessions because of lower firm productivity, equilibrium wages are lower, which raise the marginal cost of taxes (stronger tax effect). But this effect is quantitatively small. More importantly, lower productivity reduces the firm's job posting and leads to low search efficiency, which makes unemployment *less* sensitive to an extension (smaller $\partial u'/\partial d$ on the first line of 19). This decreases the social cost of benefit extensions. At the same time, lower search efficiency also makes benefit-unemployment *more* sensitive to an extension (larger $\partial u^{1'}/\partial d$ on the second and third lines), and since higher $u^{1'}$ increases search (positive $\mathbf{d}MV(s;\mathcal{O}')/\mathbf{d}u^{1'}$ on the second line), an extension raises current search more effectively now through a larger increase in $u^{1'}$. Additionally with endogenous wages, the government has an incentive to increase benefit generosity in order to dampen the fall in wages. Overall, as productivity drops the government has stronger incentives to extend UI benefits.

In response to rising unemployment, the marginal social values of search (μ_0 and μ_1 in 20) become larger as individual search is aggregated by a larger factor. As a result, the marginal social cost of unemployment $-\lambda$ becomes smaller, which lowers the extensive margin search effect in Equation (19) and allows for longer extensions. At the same time, because of higher marginal social values of search (on the second line of 19), the Markov government wants to increase search. It does so by extending UI benefits further. This may seem counter-intuitive since a longer UI extension would lower search ex ante. The key thing here is the Markov government does not consider the ex ante disincentive effects of UI extensions. It is only forward-looking and only considers the effect of a larger d on today's and future search. In this case, a larger d increases future unemployment $u^{1'}$. Higher future unemployment in turn increases today's search (positive $\mathbf{d}MV(s;\mathcal{O}')/\mathbf{d}u^{1'}$) as the private gain from search today increases and the private return to future search falls with higher future unemployment.[8] The additional wage effect becomes smaller when unemployment is higher, and because more generous benefits raise wages, the smaller wage effect reduces the

[8] $\mathbf{d}MV(s;\mathcal{O}')/\mathbf{d}u^{1'}$ nests the effects of higher future unemployment on today's search through its effects on future taxes, UI benefits, search, vacancy–unemployment ratio, and wages. Higher future unemployment raises the gain of today's search by lowering future UI benefit level and increasing future wages. It lowers the private return to future search by decreasing future vacancy–unemployment ratio and raising future search.

government's incentive to extend benefits. On net, quantitatively we find as unemployment rises, the government extends benefits.

Turning to **benefit level**. Equation (21) summarizes the welfare effects of changing the benefit level. Because of our timing assumption, the effects here are relatively simple. A redistributional effect increases consumption of the unemployed UI recipients, at the expense of higher taxes, while the positive wage bargaining effect ($\partial w/\partial b > 0$) increases the wages of employed workers.[9] In a recession, the government has incentives to reduce benefit level, because lower wages raise the marginal cost of taxes used to finance benefits. At the same time, higher total unemployment increases the measure of unemployed non-UI recipients, so the government has incentives to lower benefit level to equalize consumption. Additionally with higher unemployment, the wage bargaining effect is smaller, and so the government has an extra incentive to decrease benefit to induce lower wages.

Given the equations that characterize the UI policies, the Markov-perfect equilibrium is characterized by a system of *functional* equations (2), (3), (12)–(15), and (19)–(21). An analytical solution of this Markov-perfect equilibrium is not possible. Instead, we solve for the equilibrium numerically by approximating the government policy rules and the private-sector decision rules using the Chebyshev collocation method. The solution is a set of policy functions over the state space $\mathcal{O}$.

3.2 A comparison with Ramsey commitment policy

Although the focus of this paper is on the time-consistent UI policy, it is natural to wonder how the time-*in*consistent (Ramsey) policy differs in the same setup. The Ramsey government makes contingent policies for all future periods at time zero and is assumed to stick to these pre-determined policies. If at any time $t > 0$ the government is given the choice to break from the pre-determined policy rules, it would find it optimal to do so. In other words, policy commitment is needed to implement the Ramsey policy. This incentive to deviate from the original plan makes the Ramsey policy time-inconsistent.

Definition 3. (Ramsey problem) Given initial measures of unemployed population (u_0, u_0^1) and aggregate productivity z_0, the Ramsey government policy consists of a sequence of benefit level and duration probability $\{b_t, d_t\}_{t=0}^{\infty}$ and private allocations that solves

$$\max_{\{b_t,d_t,s_t^0,s_t^1,\theta_t,w_t,u_{t+1},u_{t+1}^1\}_{t=0}^{\infty}} \qquad \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t R(z_t, u_t, u_t^1, b_t, d_t, s_t^0, s_t^1, w_t)$$

over the set of all policies that satisfy the worker's flow equations (2)-(3), the private-sector

[9] Notice that unlike benefit duration (Equation 19), benefit level here does not affect future welfare or change current search incentive, because a change in benefit level does not directly affect future unemployment (u', $u^{1\prime}$). A higher expected *future* benefit level does lower today's search (Proposition 2).

optimality conditions (12)-(15), and the government's budget constraint (17) for all time t and aggregate shocks $\{z_t\}_{t=0}^{\infty}$.

To highlight the differences between the Ramsey commitment policy and the time-consistent Markov policy, we compare the Ramsey optimality conditions with the GEEs of the Markov government (Equations 19-21). Let $\beta^t\tilde{\mu}_{0,t}$, $\beta^t\tilde{\mu}_{1,t}$, and $\beta^t\tilde{\gamma}_t$ be the Lagrange multipliers on the time-t unemployed workers' and firm's optimality conditions (12)-(14). For an easy comparison, we write the Ramsey conditions recursively, using "–" to indicate lagged variables. The optimal Ramsey duration probability d can be characterized by[10]

$$
\begin{aligned}
0 \;=\;& u^1\left(U^1-U^0\right)+\frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial d}+\tilde{\lambda}\frac{\partial u'}{\partial d}+(1-u)U_c^e\left.\frac{\partial w}{\partial d}\right|_{\text{Nash}} \\
&+\underbrace{\frac{1}{\beta}\left[\tilde{\mu}_0^-\frac{\partial MV(s^{0-})}{\partial d}+\tilde{\mu}_1^-\frac{\partial MV(s^{1-})}{\partial d}\right]+\frac{1}{\beta}\left.\frac{\partial w}{\partial d}\right|_{\text{Nash}}\left[\tilde{\mu}_0^-\frac{\partial MV(s^{0-})}{\partial w}+\tilde{\mu}_1^-\frac{\partial MV(s^{1-})}{\partial w}+\tilde{\gamma}^-\frac{\partial MV(\theta^-)}{\partial w}\right]}_{\text{ex ante effects on private choices}} \\
&+\frac{\partial u^{1\prime}}{\partial d}\left\{\tilde{\mu}_0\frac{\partial MV(s^0)}{\partial u^{1\prime}}+\tilde{\mu}_1\frac{\partial MV(s^1)}{\partial u^{1\prime}}+\beta\mathbb{E}\left[\frac{\partial R'}{\partial u^{1\prime}}+\tilde{\lambda}'\frac{\partial u''}{\partial u^{1\prime}}\right]+\cdots\right. \\
&\left.\cdots+\beta\mathbb{E}(1-u')U_c^{e\prime}\left.\frac{\partial w'}{\partial u^{1\prime}}\right|_{\text{Nash}}+\mathbb{E}\underbrace{\left.\frac{\partial w'}{\partial u^{1\prime}}\right|_{\text{Nash}}\left[\tilde{\mu}_0\frac{\partial MV(s^0)}{\partial w'}+\tilde{\mu}_1\frac{\partial MV(s^1)}{\partial w'}+\tilde{\gamma}\frac{\partial MV(\theta)}{\partial w'}\right]}_{\text{effects of } w' \text{ on private choices today}}\right\} \\
&+\beta\mathbb{E}\frac{\partial u^{1\prime}}{\partial d}\left.\frac{\partial d'}{\partial u^{1\prime}}\right|_{u^{1\prime\prime}\text{constant}}\left\{u^{1\prime}\left(U^{1\prime}-U^{0\prime}\right)+\frac{\partial R'}{\partial \tau'}\frac{\partial \tau'}{\partial d'}+\tilde{\lambda}'\frac{\partial u''}{\partial d'}+(1-u')U_c^{e\prime}\left.\frac{\partial w'}{\partial d'}\right|_{\text{Nash}}\cdots\right. \\
&\left.\cdots+\underbrace{\frac{1}{\beta}\left[\tilde{\mu}_0\frac{\partial MV(s^0)}{\partial d'}+\tilde{\mu}_1\frac{\partial MV(s^1)}{\partial d'}\right]}_{\text{effects of } d' \text{ on private choices today}}+\underbrace{\frac{1}{\beta}\left.\frac{\partial w'}{\partial d'}\right|_{\text{Nash}}\left[\tilde{\mu}_0\frac{\partial MV(s^0)}{\partial w'}+\tilde{\mu}_1\frac{\partial MV(s^1)}{\partial w'}+\tilde{\gamma}\frac{\partial MV(\theta)}{\partial w'}\right]}_{\text{effects of } d' \text{ on private choices through } w'}\right\}, \qquad (22)
\end{aligned}
$$

where the shadow value of unemployment $\tilde{\lambda}$ is given recursively by

$$
\begin{aligned}
\tilde{\lambda} \;=\;& \beta\mathbb{E}\left(\frac{\partial R'}{\partial u'}+\tilde{\lambda}'\frac{\partial u''}{\partial u'}\right) \\
&+\beta\mathbb{E}\left.\frac{\partial d'}{\partial u'}\right|_{u^{1\prime\prime}\text{constant}}\left\{u^{1\prime}\left(U^{1\prime}-U^{0\prime}\right)+\frac{\partial R'}{\partial \tau'}\frac{\partial \tau'}{\partial d'}+\tilde{\lambda}'\frac{\partial u''}{\partial d'}+(1-u')U_c^{e\prime}\left.\frac{\partial w'}{\partial d'}\right|_{\text{Nash}}\cdots\right. \\
&\left.\cdots+\underbrace{\frac{1}{\beta}\left[\tilde{\mu}_0\frac{\partial MV(s^0)}{\partial d'}+\tilde{\mu}_1\frac{\partial MV(s^1)}{\partial d'}\right]}_{\text{effects of } d' \text{ on private choices today}}+\underbrace{\frac{1}{\beta}\left.\frac{\partial w'}{\partial d'}\right|_{\text{Nash}}\left[\tilde{\mu}_0\frac{\partial MV(s^0)}{\partial w'}+\tilde{\mu}_1\frac{\partial MV(s^1)}{\partial w'}+\tilde{\gamma}\frac{\partial MV(\theta)}{\partial w'}\right]}_{\text{effects of } d' \text{ on private choices through } w'}\right\} \qquad (23)
\end{aligned}
$$

[10] The online Appendix C3 contains the full derivation of the Ramsey optimality conditions. $\partial MV(s^1)/\partial d$ is the *partial* derivative of the worker's optimality condition (13) with respect to d and does not contain policy derivatives. In contrast, $\mathbf{d}MV(s^1;\mathcal{O}')$ in Markov problem (e.g. in Equation 19) contains policy derivatives.

and the benefit level b is characterized by

$$
\begin{aligned}
0 \quad = \quad & u^1 dU_c^1 + \frac{\partial R}{\partial \tau}\frac{\partial \tau}{\partial b} + (1-u)U_c^e \left.\frac{\partial w}{\partial b}\right|_{\text{Nash}} \\
& + \underbrace{\frac{1}{\beta}\left[\tilde{\mu}_0^- \frac{\partial MV(s^{0-})}{\partial b} + \tilde{\mu}_1^- \frac{\partial MV(s^{1-})}{\partial b}\right] + \frac{1}{\beta}\left.\frac{\partial w}{\partial b}\right|_{\text{Nash}}\left[\tilde{\mu}_0^- \frac{\partial MV(s^{0-})}{\partial w} + \tilde{\mu}_1^- \frac{\partial MV(s^{1-})}{\partial w} + \tilde{\gamma}^- \frac{\partial MV(\theta^-)}{\partial w}\right]}_{\text{ex ante effects on private choices}} \qquad (24)
\end{aligned}
$$

Because the Ramsey policies are chosen at time zero to maximize all future welfare, the government internalizes the ex ante effects of time-t policy on time-$t-1$ choices. In other words, the Ramsey government is *backward-looking*, in addition to *forward-looking* as the Markov government. These ex ante effects are captured by the lagged multipliers $\tilde{\mu}_0^-$, $\tilde{\mu}_1^-$, and $\tilde{\gamma}^-$, which are absent from the Markov optimality conditions (19)-(21). In particular, the Ramsey government considers how a generous UI policy today reduces worker's search incentive yesterday ($\partial MV(s^{1-})/\partial d < 0$). With positive wage effects ($\partial w/\partial d, \partial w/\partial b > 0$) from Nash bargaining, the Ramsey government also considers how more generous benefits today lead to higher wages today, which lower firm's vacancy posting yesterday. As a result, the steady state Ramsey benefit level and duration are less generous than the Markov policy.

During recessions when productivity is low, the Ramsey government, similar to the Markov government, also extends UI duration. Further, with lower productivity, the loss from higher unemployment today is smaller, which means lower social value of search and job creation yesterday. This ex ante effect prompts the Ramsey government to extend benefits further in response to lower productivity. As unemployment starts rising, the Ramsey government, compared to the Markov government, additionally realizes that benefit extensions discourage *more* unemployed workers from search ex ante (captured by larger $\tilde{\mu}_1^-$ and $\tilde{\mu}_0^-$ in Equation 22). This raises the marginal cost of an extension beyond the level considered by the Markov government. More specifically, a higher u_t increases the marginal cost of d_{t+1} through raising the marginal social values of time-t search and vacancy posting $\tilde{\mu}_{0,t}, \tilde{\mu}_{1,t}, \tilde{\gamma}_t$. This gives the Ramsey government an incentive to promise lower d_{t+1}. As such, compared to the Markov government, the Ramsey government has less incentive to extend (more incentive to *shorten*) benefit duration in response to higher unemployment. In other words, the Ramsey policy should be *less* countercyclical than the Markov policy, all else equal.

4 Parametrization

The model period is one month. We calibrate the parameters by matching moments of the Markov equilibrium to the empirical moments of the U.S. labor market during 1948.I-2007.IV. We do this under the assumption that the government behaves as a benevolent utilitarian welfare-maximizer making discretionary policies and the equilibrium economy with such a government mirrors the U.S. economy. It turns out that this assumption is not far from reality, as we show in the calibrated model the Markov benefit extensions mimic the U.S. policies quite closely (Section 6).

Some parameters such as preferences are chosen independently of the model. Eight parameters, including two for the productivity process, are jointly calibrated to match unconditional moments. In particular, the productivity process is not calibrated using empirical series of productivity, but determined endogenously of the model. Accordingly, when we take the model to study extensions during the Great Recession, we choose the path of productivity to match the dynamics of unemployment.

The utility function is

$$U(c,s) = \log(c) - v(s),$$

where $v(\cdot)$ is the search cost function, which we specify following the literature:

$$v(s) = \alpha \frac{s^{1+\phi}}{1+\phi},$$

with $\alpha > 0$, $v_s(s) > 0$, $v_{ss}(s) > 0$, and $v(0) = v_s(0) = 0$.

We adopt the matching function from Den Haan et al. (2000), which is also used in Hagedorn and Manovskii (2008) and Krusell et al. (2010) among others:

$$M(I,V) = \frac{V}{\left[1 + (V/I)^{\chi}\right]^{1/\chi}}, \tag{25}$$

where $I = u^1 d s^1 + (u - u^1 d)s^0$ is the aggregate job search and V is the aggregate vacancy posting in the economy. The market tightness θ is given by $\theta = V/I \equiv V/[u^1 d s^1 + (u - u^1 d)s^0]$. This matching function guarantees that both the search efficiency, $f(\theta) = \theta/\left[1+\theta^{\chi}\right]^{1/\chi}$ and the job-filling rate, $q(\theta) = 1/\left[1+\theta^{\chi}\right]^{1/\chi}$ are strictly less than 1.

The discount factor β is set to be $0.99^{1/3}$, giving a quarterly discount factor of 0.99. We calculate the average monthly job separation rate from the aggregate-level CPS data and obtain an average separation rate $\delta = 0.02$ for the period 2003.I-2007.IV.[11] We set the cost of vacancy creation κ to be 58% of monthly productivity following Hagedorn and Manovskii (2008). The level parameter in the search cost function α is normalized to 3.5.

We normalize the mean productivity to be $\bar{z} = 1$ and assume an AR(1) process for the shock z: $\log z' = \rho_z \log z + \sigma_\epsilon \epsilon$, where $\rho_z \in [0,1)$, $\sigma_\epsilon > 0$, and ϵ are i.i.d. standard normal random variables. We jointly calibrate ρ_z and σ_ϵ with six other parameters to match eight

[11] Although some may argue that the U.S. economy during 2003.I-2007.IV is *above* the long-run trend, we believe it is an appropriate period to target for the labor market, especially because of the secular downward trend in job separation rate documented by, for example, Fujita (2018). Given this trend, using the average job separation rate over a longer horizon would overestimate the recent steady-state numbers.

target moments.[12] The six other parameters are (1) the value of nonmarket activity h, (2) the curvature parameter of search cost ϕ, (3) the matching function parameter χ, (4) the probability that a newly unemployed worker is benefit-eligible ξ, (5) the steady state worker's wage bargaining power ζ, and (6) the cyclicality of bargaining power ϵ_ζ.[13]

The eight target moments are: (1) the average job finding rate,[14] (2) the effect of a one-week benefit extension on the unemployment duration of UI recipients,[15] (3) the proportion of UI recipients among unemployed workers, (4) the vacancy–unemployment ratio, (5) the elasticity of wages with respect to productivity, (6) the long-run auto-correlation of unemployment, (7) the standard deviation of vacancy–unemployment ratio, and (8) the standard deviation of unemployment.[16]

Intuitively, the average job finding rate identifies the matching parameter χ; the micro-effect of benefit extension pins down the curvature of search disutility ϕ; the proportion of covered unemployment pins down the probability of gaining UI status ξ; the vacancy–unemployment ratio pins down the worker's wage bargaining power ζ; the wage-productivity elasticity pins down the cyclicality of bargaining power ϵ_ζ; the auto-correlation of unemployment identifies the persistence of the productivity process ρ_z; and the standard deviations of vacancy–unemployment ratio and unemployment jointly identify the value of nonmarket activity h and the standard deviation of innovation to the productivity process σ_ϵ.

The average job finding rate is taken to be 0.40 and vacancy–unemployment ratio is 0.65. Using Department of Labor (DOL) reported population of weekly continuing UI claims and unemployment population we obtain an average proportion of UI-covered unemployment of 0.45. We take the response of unemployment duration to benefit extension from micro-estimates in the literature. The estimated effect ranges from an average increase of 0.08

[12] We use a derivative-free algorithm for least-squares minimization to perform joint calibration. See Zhang et al. (2010) for details.

[13] A cyclical bargaining power of the form $\zeta_t = \zeta + \epsilon_\zeta(z_t - \bar{z})$ helps to dampen the response of wage fluctuations over business cycle. A countercyclical worker's bargaining power $\epsilon_\zeta < 0$ raises (lowers) worker's bargaining power during recessions (booms) to reduce the size of changes in wages over the cycle. Our calibrated ϵ_ζ implies a 1% drop in z from steady state leads ζ to increase from 0.58 to 0.61. A very small worker's bargaining power as used in Hagedorn and Manovskii (2008) and Mitman and Rabinovich (2015) can also reduce wage fluctuations. But in our model, a small ζ leads to unstable Markov equilibria, and so we use the cyclicality of ζ similar to Jung and Kuester (2015).

[14] The average job finding rate in the model $\bar{s}f(\theta)$ is calculated using the *average* search $\bar{s} = I/u \equiv [u^1 d s^1 + (u - u^1 d)s^0]/u$.

[15] The effect of 1-week extension is computed at the steady state as the partial equilibrium effect of 1-week extension from the steady-state level on the benefit recipients' search s^1, translated into unemployment duration $1/(f(\theta)s^1)$ when all other objects are held at their steady state levels.

[16] The calibrated *latent* productivity process is very close to the measured labor productivity. The (HP-filtered and seasonally adjusted) average real output per employed person in the non-farm business sector (measured labor productivity) has a quarterly auto-correlation of 0.762 and an unconditional standard deviation of 0.013, which translated to a monthly frequency means $\rho = 0.968$ and $\sigma_\epsilon = 0.006$. Our calibration of the latent productivity process yields $\rho = 0.975$ and $\sigma_\epsilon = 0.0061$, slightly higher persistence.

weeks (Card and Levine 2000) to more than 0.3 weeks (Johnston and Mas 2018) in response to a one-week benefit extension.[17] We take the median value of 0.16 as the calibration target. We use numbers standard in the literature for the second-order target moments.

Table 1 reports these internally calibrated parameters and calibration targets. The calibrated model delivers an untargeted benefit duration of 23 weeks, compared to the benefit duration of 26 weeks in the U.S. during normal times. The model-generated steady state benefit replacement ratio is 57%, slightly higher than the U.S. replacement ratio of 40-50%.[18]

5 Quantitative Equilibrium Results

This section presents the quantitative equilibrium Markov UI policy and highlights its differences with the Ramsey commitment policy.

5.1 Markov equilibrium UI policy

The discussion of Section 3.1 provides some intuition for how Markov UI policies change in response to changes in unemployment and productivity. Here we show the Markov equilibrium UI policy functions based on the calibrated model. Because the policy rules are functions of three state variables, we show plots along each of the three states while holding the other two states at their steady states. Figure 1 plots the UI policy rules over productivity (Panel A), total unemployment (Panel B), and benefit-eligible unemployment (Panel C). In each plot, the solid line represents the policy rule, and the dashed vertical line marks the steady-state unemployment or productivity. We express UI duration in weeks, $4/(1-d)$.

Consistent with the intuition of Section 3.1, UI duration is longer when productivity is lower or when unemployment is higher. UI benefit level is higher when productivity is higher or when unemployment is lower. Overall, the equilibrium UI duration is countercyclical, whereas the benefit level is slightly procyclical.

5.2 A comparison with Ramsey UI policy

As pointed out in Section 3.2, because of commitment to future policies, the Ramsey government internalizes the effects of current policy on past incentives. In particular, the Ramsey government realizes that an expectation of generous benefits (higher benefit level or longer benefit duration) at time t creates disincentives for UI recipients to search at time $t-1$. As a result, the steady state Ramsey benefits are less generous than the Markov benefits.

Table 2 compares the steady states of the Ramsey vs Markov economies. The Ramsey steady state UI duration is shorter (16 weeks vs 23 weeks) and benefit level is lower (0.32 vs

[17] The online Appendix B summarizes these estimates.

[18] The high benefit replacement ratio is partly because with endogenous wages, the government can raise benefits to raise wages. With the alternative exogenous wage rule (11), replacement ratio is much lower.

0.56), exactly because the Ramsey government takes into account the ex ante disincentives of generous policies. The shorter duration and lower benefit level reduce search disincentive, so search by UI recipients s^1 is significantly higher, and the proportion of UI recipients is much lower in the Ramsey economy. As a result, unemployment is lower (4.34% vs 4.85%).

Figure 2 plots the Ramsey UI policy. Consistent with the intuition, Panel A shows that when productivity is higher, the Ramsey UI duration is shorter and benefit level is higher, similar to the Markov UI policies. The key difference is the response to changes in unemployment. Because the Ramsey government cares about ex ante incentives, the lagged multipliers $\tilde{\mu}_0^-$, $\tilde{\mu}_1^-$, and $\tilde{\gamma}^-$ appear in the Ramsey government's problem (Equations 22-24), and are also part of the state space of the Ramsey UI policy. Consistent with the discussion of Section 3.2, Panel C shows that as unemployment becomes higher, the multipliers, which capture the marginal social values of search and job posting, become larger. Panel B shows that as these lagged multipliers increase, the UI duration falls. Taken together, higher lagged unemployment raises the lagged marginal social values of search and job posting, leading to a lower UI duration. This dependence on lagged unemployment through lagged multipliers is absent for the Markov policy.

The last two columns of Table 2 compares the volatility of key variables in the Markov and Ramsey economies. Notably, the Ramsey UI duration is much less volatile. This is because the Ramsey UI duration is longer when productivity is lower or unemployment is lower, and productivity and unemployment are (closely) negatively correlated, so the size of the overall change in UI duration is muted. Notice that because the Ramsey policy is designed to offset the ex ante disincentives, search, vacancy–unemployment ratio, and unemployment are also less volatile compared to the Markov economy. Finally, over the long-run, UI duration policies in both the Markov and Ramsey economies are negatively correlated with productivity z, but it is more countercyclical in the Markov equilibrium. This is because while the duration policy is positively correlated with unemployment in the Markov equilibrium, it is negatively correlated with unemployment in the Ramsey solution. This suggests the two policies will likely differ more in an environment where unemployment is persistently high such as during the Great Recession.

5.3 Response to a one-time productivity shock

We next look at the dynamic responses in both UI policy and the labor market to a 1% drop in productivity. Because the Markov and Ramsey steady states are quite different, we plot the deviations of variables from their respective steady states in Figure 3. This exercise highlights the *qualitative* differences between the two economies. Later when we use the model to look at the Great Recession in Section 6 we explore both the quantitative and qualitative differences.

Consistent with the policy function plots, both the Markov and Ramsey UI durations increase and benefit levels fall in response to the initial drop in productivity. As productivity recovers and the unemployment rises, the Markov UI duration falls gradually back to the steady state, since the effects of rising unemployment and productivity work in opposite directions. The Ramsey government, in contrast, lowers UI duration drastically below the steady state to reduce the increasing ex ante search disincentives as unemployment rises.

Because of dynamically different UI duration policies, responses in the economy are also quite different. On the intensive margin, search of UI recipients s^1 falls substantially in the first period in the Markov economy, a combined effect of lower vacancy–unemployment ratio and longer UI duration. In contrast, in the Ramsey economy s^1 rises above the steady state level initially because of lower benefit levels and an anticipated reduction in UI duration. Wages fall in both economies, a result of lower productivity. With endogenous wages, the Ramsey government internalizes the ex ante effects through expected future wages, and so as unemployment rises, the Ramsey government uses UI policy to reduce wages more to stimulate vacancy posting. As a result, the vacancy–unemployment ratio recovers faster in the Ramsey than the Markov economy. The higher vacancy ratio further encourages search.

On the extensive margin, higher UI duration in the Markov economy raises the proportion of UI recipients above the steady state. In the Ramsey economy, this proportion quickly falls below the steady state level as the government cuts UI duration. Both the intensive and extensive margin effects contribute to the different responses in unemployment. Unemployment rises in both economies but much more in the Markov economy, and recovery is also much slower in the Markov economy.

5.4 A brief comparison with Mitman and Rabinovich (2015) (MR)

The dynamic properties of the Ramsey UI duration here are consistent with those in MR, falling in both productivity and unemployment. Benefit level here increases when productivity is higher, whereas it falls in MR. This difference is driven by different assumptions on government budget. While we assume balanced government budget each period, MR allows unbalanced government budget within a period. When productivity is low, the burden of taxation is heavier with a balanced budget, and the government has more incentive to reduce benefits. Because of this difference, in response to a negative productivity shock, benefit level falls in the first period here and search by UI recipients rises initially, whereas in MR benefit level increases initially and search is always below the steady state. Overall, with a balanced budget, the Ramsey policy is even more stringent during recessions.[19]

[19] In Section 6.2, we explore a simple way to introduce relaxed government budget constraint by allowing the marginal tax cost of UI to be lower during recessions. In that case, the government still lowers UI benefit

6 UI Duration Extensions in Recessions

In this section we use the time-consistent (Markov) equilibrium to look at UI extensions during recessions in the U.S. Using calibrated shock series, the time-consistent UI policy can generate extensions close to those seen in the U.S. For comparisons, we look at two counterfactual policies: 1) the Ramsey optimal commitment policy, and 2) an acyclical policy where the government keeps UI policy unchanged.

6.1 Empirical evidence of UI benefit extensions in recessions

We first document some patterns in how UI duration changes during recessions. These changes are driven by changes in UI legislation, and the legislation changes only affect the length of UI benefits awarded to unemployed workers and not the replacement ratio. We use the term *potential UI duration* to refer to the legislated length of UI benefits awarded to workers. The actual length of benefits used by a worker depends on his unemployment duration and is bounded above by the potential UI duration.

UI duration and unemployment. We document the variations in the potential UI duration during each recession since the 1970s. Panel A of Figure 4 plots the variations in unemployment and UI duration during all five recession episodes.[20] The shaded regions mark the National Bureau of Economic Research (NBER) official recession dates. For each recession episode, the dotted red line (right axis) plots the unemployment rate, and the solid blue line (left axis) plots the potential UI duration in weeks. The timing and the size of changes in UI duration follow the specifics of the federal unemployment compensation laws, published on the U.S. Department of Labor Employment and Training Administration (DOLETA) website. Two things are worth noting. First, during all recession episodes, UI duration reached its highest level around the time unemployment peaked. Second, comparing across recessions, the recession with higher unemployment is in general associated with longer UI duration extensions, except for the 1980s recession.

Frequency of UI duraion policy changes. Because more detailed data are available for the Great Recession, we document the frequency of legislation on UI policy during and following this recession in Panel B of Figure 4. The vertical dotted lines indicate the timings of UI-related legislations. Each legislation specifies how and when UI duration policy will be changed (e.g. extended by 13 weeks). These legislations are summarized in the online Appendix A. Notice that the frequency of legislation increased substantially from the mid-2008, especially from the late-2009, to 2011. This suggests that UI extensions during recessions

level when productivity falls, but by less than in the baseline, which is consistent with the intuition here.

[20] The recession from January to July 1980 was both shorter and milder than the other recessions. In addition, it was followed immediately by the much longer recession from July 1981 to November 1982. We therefore leave out the former recession period.

are discretionary policy as opposed to pre-determined policy rules.

Weighted UI duration. While UI extension laws during recessions are passed at the federal level, whether a state receives federal funding for certain extensions depends on the state's insured unemployment rate (IUR) and total unemployment rate (TUR). We use these two statistics to determine whether each state was eligible for UI extensions in the month that a UI-related legislation was passed during the Great Recession. This gives us a more accurate picture of the impact of the UI extensions. We then create an aggregate measure of time-varying UI extensions as an empirical counterpart for our quantitative exercise. Following Albertini and Poirier (2015), we weight each state's potential UI duration ($dur_{s,t}$) using its total insured unemployed workers ($InsurUnemp_{s,t}$), then sum up the weighted durations across states:

$$D_t = \sum_s dur_{s,t} \times \frac{InsurUnemp_{s,t}}{\sum_s InsurUnemp_{s,t}}.$$

The online Appendix A provides more details on the IUR and TUR criteria and the construction of this weighted measure. Panel B of Figure 4 plots the weighted UI duration (dashed blue line).

6.2 The Great Recession

Shock and model fit. Consistent with the calibration strategy, we calibrate the latent productivity path to match the observed path of unemployment rate. It turns out a piecewise linear productivity path consisting of a drop, a flattening out and a slower recovery generates a good fit for the unemployment.

Figure 5 shows that given the shocks the model-generated unemployment (solid blud line) matches data (dashed black line) by construction. The UI duration endogenously chosen by the Markov government matches the general shape of its data counterpart. UI duration in the model rises from its steady state to 70 weeks in mid-2009, compared to the data counterpart of 90 weeks. There is some mismatch in the timings of the rise and fall of UI extension between model and data, which may be attributed to political frictions that make it harder to change the policy direction in reality.

We provide three measures of replacement ratio from data. One is a weighted legislation-based measure, computed using the state law-specified proportion of a worker's base period wage that he gets as weekly benefit amount in unemployment, weighted by the insured unemployment in each state and aggregated. In addition, we provide two empirical measures based on actual wage and weekly benefit amount data from the Unemployment Insurance Benefit Accuracy Measurement (BAM) dataset.[21] The model-generated replacement ratio

[21] Using the formula published on the DOLETA website, we construct two empirical measures of replacement ratio. Replacement Ratio 1 (dashed black line) = Weighted Average of: Weekly Benefit Amount /

(b/w) is higher than all three measures, but consistent with the two empirical measures it falls in the middle of the period. The legislation-based measure is flat, since states do not usually change UI laws to adjust replacement ratio. In addition, the model-generated proportion of unemployed workers on benefits matches the general pattern in the data.[22]

Comparison of UI policy regimes. Figure 6 compares the Markov UI policy to two alternate UI policy schemes: the acyclical policy and the Ramsey policy. The question we ask here is what are the effects of *switching to* the alternate policy scheme before the start of the recession. With the acyclical policy, the government commits to not changing the UI policy. With the Ramsey policy the government optimizes all future policies in the period before recession and has commitment to carry out these policies at later dates. Note that while the Markov and Ramsey policies are equilibrium outcomes, the acyclical policy is not.

In all three economies lower productivity leads to lower wages and lower vacancy–unemployment ratios. With the acyclical policy (dashed light blue line), search falls in the recession because lower wages reduce the value of employment and the lower vacancy–unemployment ratio reduces the return to search.[23] The proportion of UI recipients among all unemployed workers also falls, even without any change in UI duration. Lower individual search leads to lower average search, and together with lower vacancy–unemployment ratio, leads to rising unemployment.

The Markov government (solid blue line) extends UI duration and lowers benefit level during the recession. With the Markov policy, the expectation of UI extensions in recessions creates search disincentives for UI recipients, and this effect outweighs the anticipated reduction in benefit level. The rising UI duration also dampens the fall in wages, and so the vacancy–unemployment ratio falls more, which further discourages search in the Markov equilibrium. As a result, s^1 falls more than under the acyclical policy (intensive margin effect). Because of UI extensions, the proportion of UI recipients rose to 55% (extensive margin effect). Both lower search and rising UI-recipiency rate contribute to a larger fall in average search in the Markov equilibrium. Taken together, the unemployment increases by an additional 1.2 percentage points compared to the economy with the acyclical policy.

(Normal Hourly Wage x 40 Hrs.). Replacement Ratio 2 (dotted black line) = Ratio of: Weighted Average Weekly Benefit Amount / (Weighted Average Normal Hourly Wage x 40 Hrs). The first is the average of ratios, and the second is the ratio of averages. These two measures are lower than the legislation-based ratio, because the weekly benefit amount is subject to minimum and maximum dollar amounts that are decided by states. The two empirical measures use actual benefit amounts paid that reflect the lower and upper bounds, and so they are likely more accurate measures of the actual replacement ratio.

[22] In the long-run, the model-generated correlation between proportion of UI recipients and unemployment is 0.8, compared to 0.48 in the data since 2000. The model-generated correlation of total UI spending and unemployment is 0.85, relative to 0.68 in the data.

[23] Procyclical search is a feature of the canonical Diamond-Mortensen-Pissarides model. The empirical findings on the cyclicality of search effort are mixed. We provide a discussion in the online Appendix D4.

Turning to the Ramsey policy (dotted red line), the government increases UI duration slightly from 16 to 17 weeks at the start of the recession in response to the negative productivity shock and while unemployment is still low. But as the unemployment rises, the Ramsey government reduces UI duration to 10 weeks to create search incentives for the rising number of unemployed workers. Benefit level follows a similar path as duration. The anticipations of shorter benefit duration and lower benefit level partially offset the search disincentives due to lower wages. At the same time, the shorter UI duration and lower benefit level decrease wages more compared to the Markov and acyclical economics. Lower wages dampen the fall in the vacancy–unemployment ratio, which further encourages search. As a result, UI recipients reduce search less than in the other two economies (intensive margin). Shorter UI duration also reduces the proportion of UI recipients, which falls more than under the acyclical policy (extensive margin). Both the intensive and extensive margin effects lead to a smaller fall in average search, and a smaller rise in unemployment (increases to 7.1%) compared to both the Markov (10%) and acyclical policies (8.8%).

If the government switched from the Markov policy to the Ramsey policy after the initial negative productivity shock realized, lifetime welfare would be 0.12% higher, compared to a 0.011% welfare gain if the government were to follow the acyclical policy.[24] Both alternate policies require some kind of commitment to be credible, as otherwise the private sector would *expect* the government to deviate from the plan and implement the Markov policy.

Effects of endogenous wages. There is an active debate about the effects of UI benefits on wages. Without taking a stand in this paper, we have adopted a version of the Nash bargaining rule in the baseline. An alternative is the exogenous wage rule (11), where wages only depend on productivity through an elasticity parameter. With exogenous wages, governments cannot use UI policy to affect wages and, through wages, firm's job posting.

We re-calibrate the model under this alternative wage rule. Details are in the online Appendix D1. Because the Markov government cannot use UI benefit to increase wages, the Markov benefit level is substantially lower than the baseline.[25] The steady state replacement ratio is 0.36, compared to 0.57 in the baseline.[26] The Ramsey benefit level is similar to the baseline, because in the baseline the Ramsey government considers both the current and the ex ante effects of higher benefit on wages, and these two effects offset each other.

[24] We compute the consumption equivalent variation based on the utilitarian welfare function (18). To be more specific, we compute the percent change in lifetime consumption — of all workers, employed and unemployed — that would make welfare under the Markov policy equivalent to switching to the alternate policy. This welfare calculation includes the transition path.

[25] Note that because the model is re-calibrated, it is hard to have a direct comparison with the baseline model results. The comparisons in this discussion are more intuitive than precise.

[26] The steady state UI duration in the Markov economy is higher with exogenous wages: 28 weeks compared to 23 in the baseline. One reason is with a lower steady state benefit level b, the government can afford (in terms of tax cost) to have a longer UI duration.

Figure 7 presents simulated results during the Great Recession. Panel A shows that with exogenous wages the Markov government extends UI duration up to 80 weeks, while the replacement ratio falls slightly, similar to the baseline. Panel B compares the policy responses in different economies. Because the Ramsey government cannot use UI policies to lower wages and dampen the fall in vacancy–unemployment ratio during the recession, the cuts in the Ramsey UI duration and benefits are smaller compared to the baseline. Accordingly, the difference in unemployment between the Markov and Ramsey economies is also slightly smaller — 2.7 compared to 2.9 percentage points in the baseline.

Unbalanced government budget. We have so far assumed period-by-period balanced government budget. While the assumption helps make the Markov equilibrium tractable, it implies that in recessions, lower productivity and wages raise the marginal cost of taxes and the government has to cut UI benefits to lower taxes. In reality sometimes, the government can run a deficit (through accumulating debt) during a recession and expect to pay back after the recession. This gives the government additional capacities to increase the generosity of UI benefits during recessions. To capture this effect in a tractable way, we allow UI benefits to have smaller impacts on taxes in recessions by adding *cyclical wedges* to the derivatives of tax with respect to b and d. Define the modified marginal effects of b and d on tax:

$$\hat{\tau}_b = \partial\tau/\partial b + \underbrace{\epsilon_b(z-\bar{z})}_{\text{cyclical wedge}}, \quad \hat{\tau}_d = \partial\tau/\partial d + \underbrace{\epsilon_d(z-\bar{z})}_{\text{cyclical wedge}}, \quad \epsilon_b, \epsilon_d > 0.$$

The cyclical wedges make increasing benefits less expensive during recessions (e.g. $\hat{\tau}_b$ is smaller relative to $\partial\tau/\partial b$ when $z < \bar{z}$). Intuitively, in a recession the marginal cost of raising b becomes smaller relative to the baseline, which allows the Markov government the *capacity* to not reduce b as much. A similar effect of increased capacity applies to the Ramsey problem. In addition, a smaller $\hat{\tau}_b$ in recessions reduces the private marginal return to search, and increases the ex ante disincentive effects of b on search, relative to the baseline. This stronger ex ante effect reduces the Ramsey government's willingness to increase benefit generosity in recessions, which partially offsets the effect of increased capacity on benefits. The main effects of $\hat{\tau}_d$ are similar to $\hat{\tau}_b$: increased capacity for both Markov and Ramsey governments, and lower incentive for the Ramsey government to increase d in recessions.[27]

Setting $\epsilon_b = \epsilon_d = 0.01$ while keeping all other parameters unchanged from the baseline, Panel A of Figure 8 shows that consistent with the intuitions, the model Markov economy generates larger UI extensions and smaller benefit cuts (solid blue lines) compared to the baseline (dotted purple lines): UI duration increases to 80 instead of 70 weeks, and replacement ratio drops to 0.55 instead of 0.53 during the Great Recession. As a result, unemployment is slightly higher than the baseline. Panel B plots the different policies in

[27] The additional effects of $\hat{\tau}_d$ on future capacity and incentives are less clear intuitively, and so we resolve to a numerical exercise.

this alternative setup. The general patterns are consistent with the baseline. Similar to the Markov policy, the Ramsey UI policies are more generous than the baseline, with smaller falls in UI duration and benefit level.

7 Conclusion

During recessions, the U.S. government substantially increases UI duration. This paper studies UI extensions during recessions when the government does not have commitment to future policies. Calibrated to the U.S. economy, the time-consistent UI extensions are quantitatively consistent with the extensions during the Great Recession. Compared to the optimal commitment (Ramsey) policy, the time-consistent UI extensions raised the unemployment rate by an additional 2.9 percentage point, and switching to the optimal commitment policy improves welfare.

We consider this paper an application of the time-consistent Markov-perfect equilibrium to a search-matching environment. We focus on recessions, because the time-consistent policy is likely especially relevant during recessions due to heightened political pressure to forgo prior promises and implement discretionary policies. While UI policy, and in particular, UI extension has been and likely will be a popular and contentious labor market policy, changes in other labor market policies (e.g. hiring subsidies) may have interesting interactions with UI extensions. Considering these other policies in combination with UI policy in a time-consistent setting will provide a more comprehensive policy recommendation.

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Tables and Figures

Table 1: Calibrated Parameters and Moments

Parameter	Description	Value
h	Value of nonmarket activity	0.59
χ	Matching parameter	1.6
ϕ	Search cost curvature	3.37
ξ	Prob. newly unemployed is benefit eligible	0.55
ζ	Steady state worker's bargaining power	0.58
ϵ_ζ	Cyclicality of bargaining power	-2.9
ρ_z	Persistence of latent productivity	0.975
σ_ϵ	Std dev of innovation to productivity	0.0061
Target Moments	**Data**	**Model**
Average job finding rate $\bar{s}f(\theta)$	0.40	0.39
Vacancy–unemployment ratio v/u	0.65	0.68
% UI recipients among unemployed u^1d/u	0.45	0.42
Δunemp duration/ΔUI duration	0.16	0.17
Std dev of vacancy–unemp ratio v/u	0.257	0.272
Std dev of unemployment u	0.125	0.126
Elasticity of wages with respect to z	0.45	0.48
Auto-correlation of unemployment u	0.87	0.86
Non-Target Policy Moments	**Data**	**Model**
Average UI Duration	26	23
UI replacement ratio	40-50%	57%

Note: See text for how model-generated moments are calculated. Seasonally adjusted unemployment series, u, is constructed by the BLS from the CPS. Vacancy posting, v, is Barnichon (2010)'s spliced series of seasonally adjusted help-wanted advertising index constructed by the Conference Board and the job posting data from the JOLTS. Both u and v are quarterly averages of monthly series. All second-order moments are reported in logs as deviations from an HP-filtered trend with smoothing parameter 1,600.

Table 2: Equilibrium Comparison: Markov versus Ramsey Policy

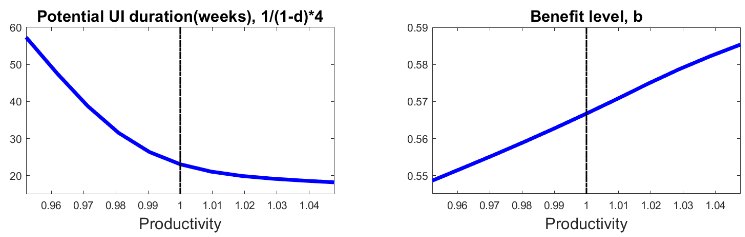
Statistics	Mean		Standard deviation	
	Markov	Ramsey	Markov	Ramsey
Benefit level, b	0.56	0.32	0.01	0.114
UI duration(weeks), $4/(1-d)$	23	16	6.76	0.86
Wages, w	0.978	0.977	0.009	0.009
UI recipient search, s^1	0.43	0.57	0.090	0.025
Non-recipient search, s^0	0.67	0.67	0.024	0.007
Vacancy–unemployment ratio, v/u	0.64	0.72	0.272	0.071
Proportion of UI recipients, u^1d/u	0.42	0.33	0.08	0.25
Unemployment, $u(\%)$	4.85	4.34	0.126	0.08

Statistics	Correlation with z		Correlation with u	
	Markov	Ramsey	Markov	Ramsey
Benefit level	0.92	0.95	-0.72	-0.83
UI duration(weeks)	-0.74	-0.27	0.65	-0.12

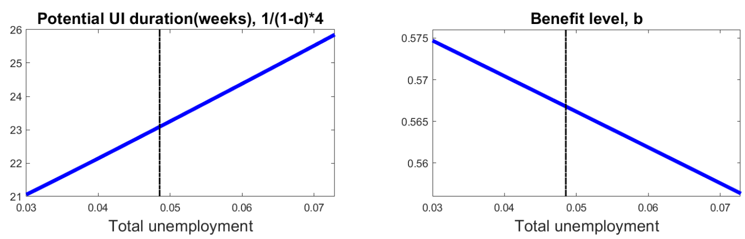
Note: Statistics of Markov and Ramsey equilibria are computed using the same parameters in Table 1. Means are reported in levels, standard deviations are reported in logs as quarterly deviations from an HP-filtered trend with a smoothing parameter of 1600.

Figure 1: Markov equilibrium UI policy functions

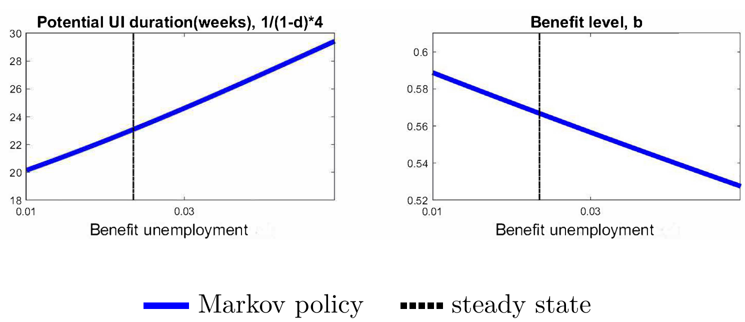
Panel A: Over productivity, z



Panel B: Over total unemployment, u



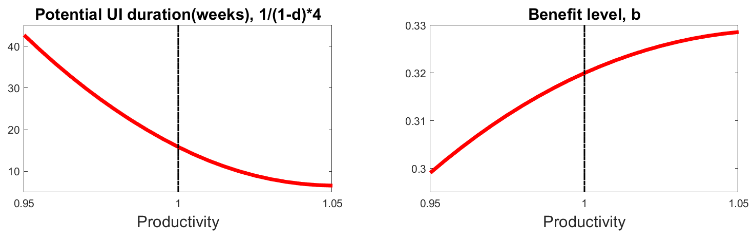
Panel C: Over benefit unemployment, u^1



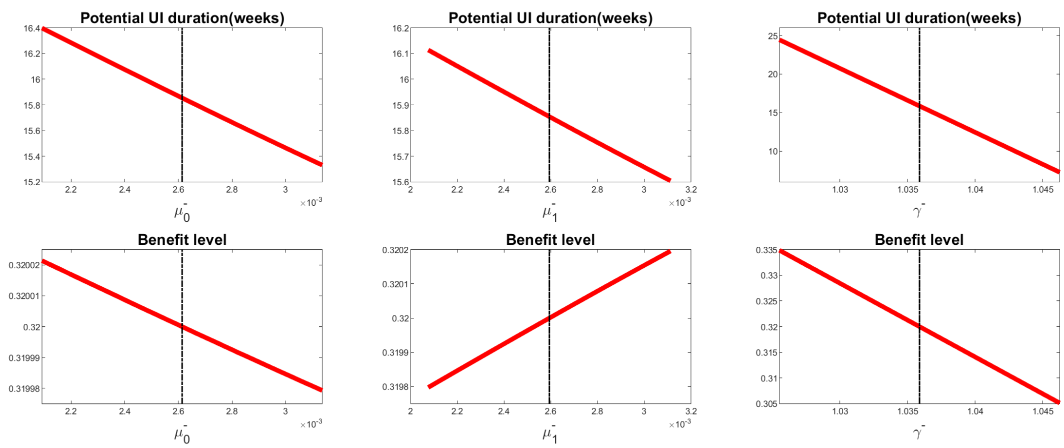
Note: This figure plots the Markov equilibrium UI policy functions (potential duration and benefit level) over each of the three states, holding the other two states at their steady states. The dotted vertical line marks the steady state of the changing state variable. Potential UI duration (in weeks) is computed based on the variable d as $1/(1-d) \times 4$.

Figure 2: Ramsey UI policy functions

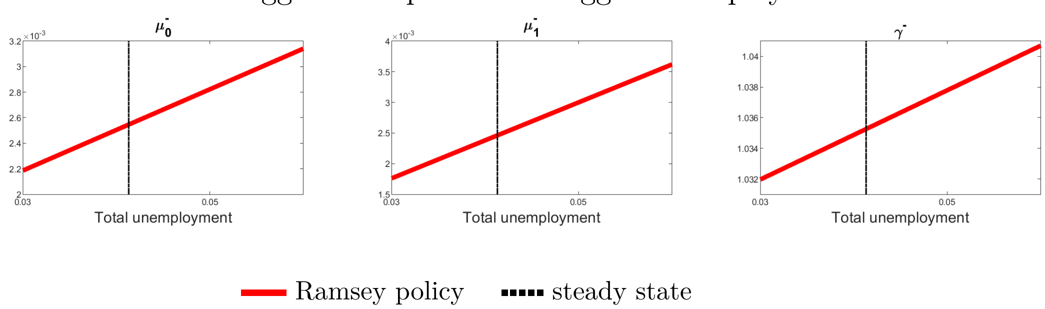
Panel A: UI Policy over productivity z



Panel B: UI Policy over lagged multipliers

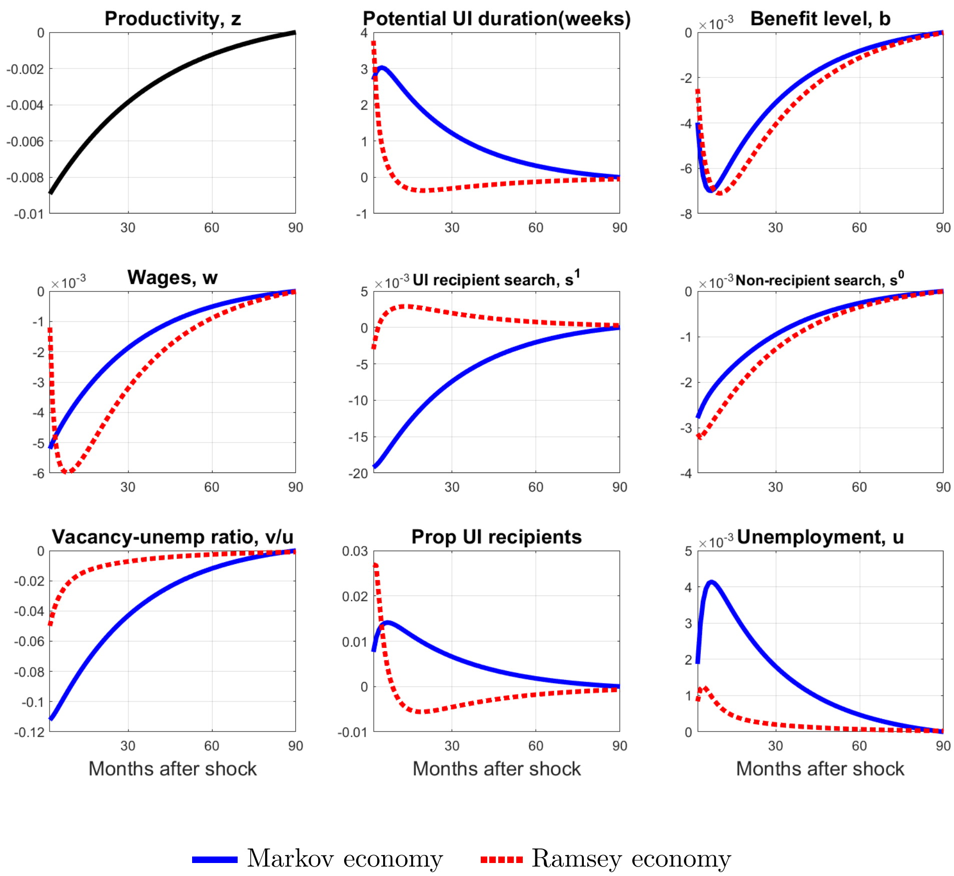


Panel C: Lagged multipliers over lagged unemployment



Note: This figure plots the Ramsey UI policy functions (potential duration and benefit level) over selected states, holding the other states at their steady states. The dotted vertical line marks the steady state of the changing state variable. Potential UI duration (in weeks) is computed based on the variable d as $1/(1-d) \times 4$. Unlike Markov policy, the Ramsey UI policies depend on *lagged* unemployment through lagged multiplier: the UI policies depend on *lagged* multipliers (Panel B); these multipliers in turn depend on *lagged* unemployment (Panel C).

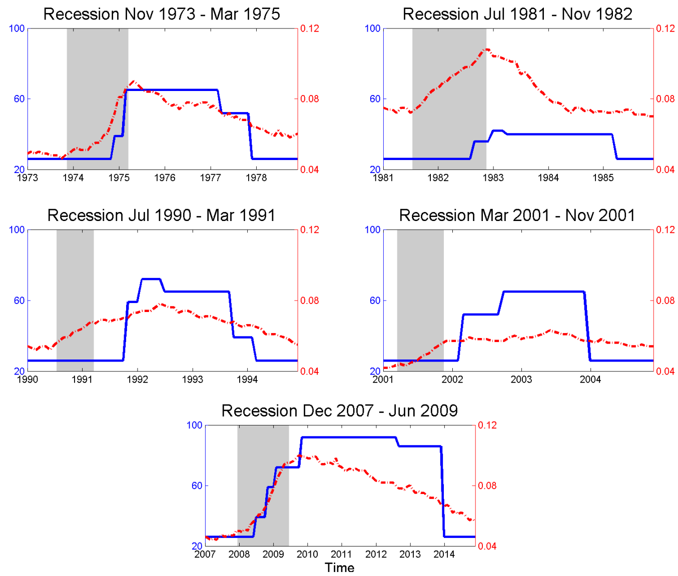
Figure 3: Responses (deviations from steady state) to a 1% drop in productivity.



Note: This figure plots the responses of the Markov and Ramsey economies to a 1% drop in productivity z. Potential UI duration (in weeks) is computed based on the variable d as $1/(1-d) \times 4$. The proportion of UI recipients (among unemployed workers) is calculated as $u^1 d/u$.

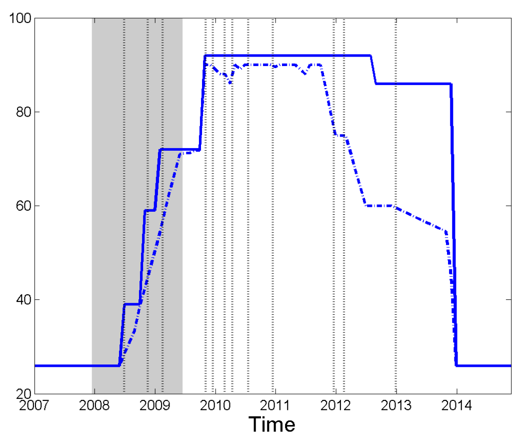
Figure 4: Empirical patterns of UI duration changes during recessions since 1970s.

Panel A: Changes in UI duration (left axis) and unemployment (right axis) during recessions.



Data: Potential UI duration (weeks) Data: Unemployment rate

Panel B: Changes in UI duration and timing of UI-related legislation during the Great Recession.



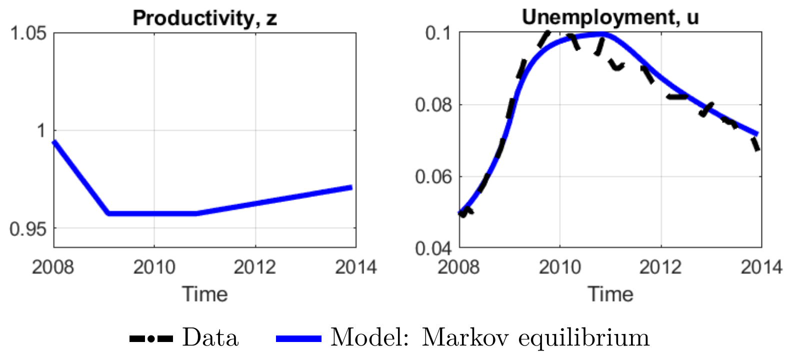
Data: Potential UI duration (weeks) Data: Weighted potential UI duration (weeks)

Data: UI legislation dates

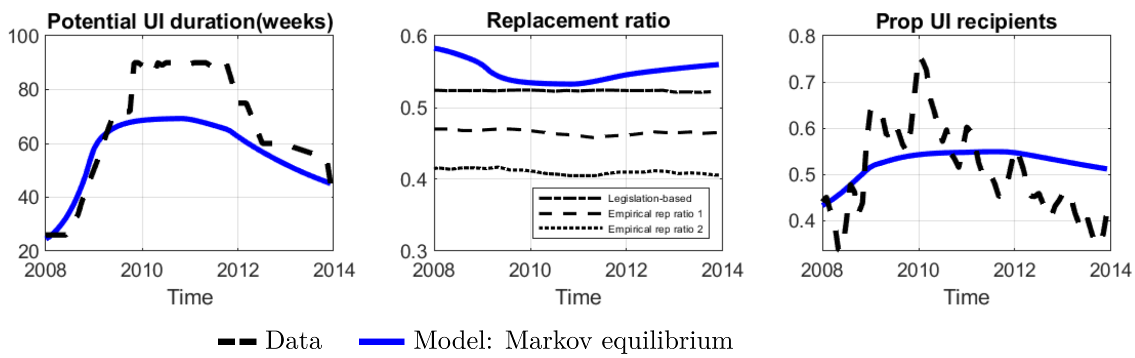
Note: The shaded regions mark the NBER recession periods. The *potential UI duration* is the maximum length of UI benefits (in weeks) an unemployed worker qualifies for. It is typically 26 weeks and extended at the federal level through UI legislation changes during recessions since the 1970s. We plot the changes in legislated UI duration for each recession. In practice, a state may not get federal funding for the entire legislated extensions if its (insured) unemployment rate is not high enough in a month. The *weighted potential UI duration* in Panel B is a cross-state weighted measure based on the actual UI extensions that a state gets at any time. The vertical dotted lines mark the dates of UI-related legislation during the Great Recession. Because laws on replacement ratio do not usually change during these recessions, we do not document changes in replacement ratio here.

Figure 5: Model fit: Exogenous shock, UI policy and unemployment in the Great Recession.

Panel A: Productivity and unemployment rate.

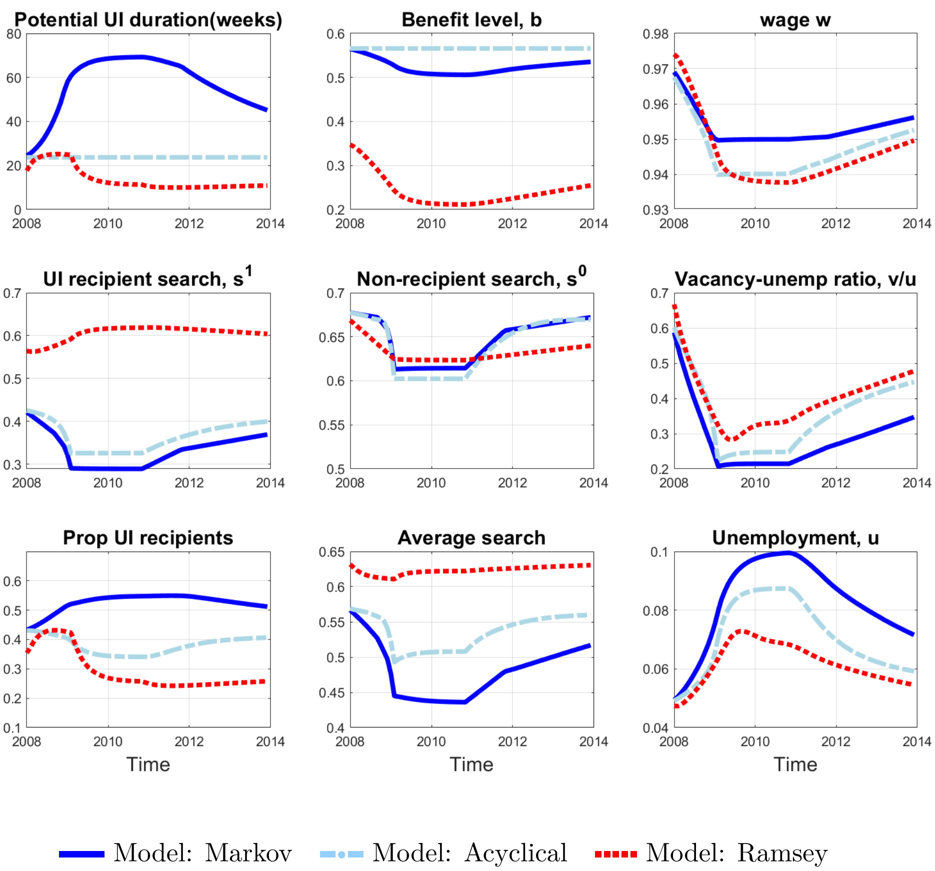


Panel B: UI duration, replacement ratio, and proportion of unemployed receiving UI benefits.



Note: In Panel A the productivity path is chosen so that the path of unemployment in the Markov-perfect equilibrium matches data. In Panel B the model-generated potential UI duration is computed as $1/(1-d)\times 4$; its empirical counterpart is the weighted potential UI duration measure in Figure 4 Panel B. The replacement ratio is computed as b/w in the model. We provide three data counterparts. One is a weighted legislation-based measure using the proportion of base period wage a worker gets as weekly benefit amount as specified in states' UI laws, and weighted by insured unemployment in each state. The two empirical measures are constructed using actual wage and weekly benefit amount data from the Unemployment Insurance Benefit Accuracy Measurement (BAM) dataset available on the DOLETA website, and following Department of Labor's published methods. The proportion of UI recipients among unemployed workers is computed as $u^1 d/u$ in the model. The data counterpart is the ratio of UI recipients (both regular and extension programs) over total unemployed population.

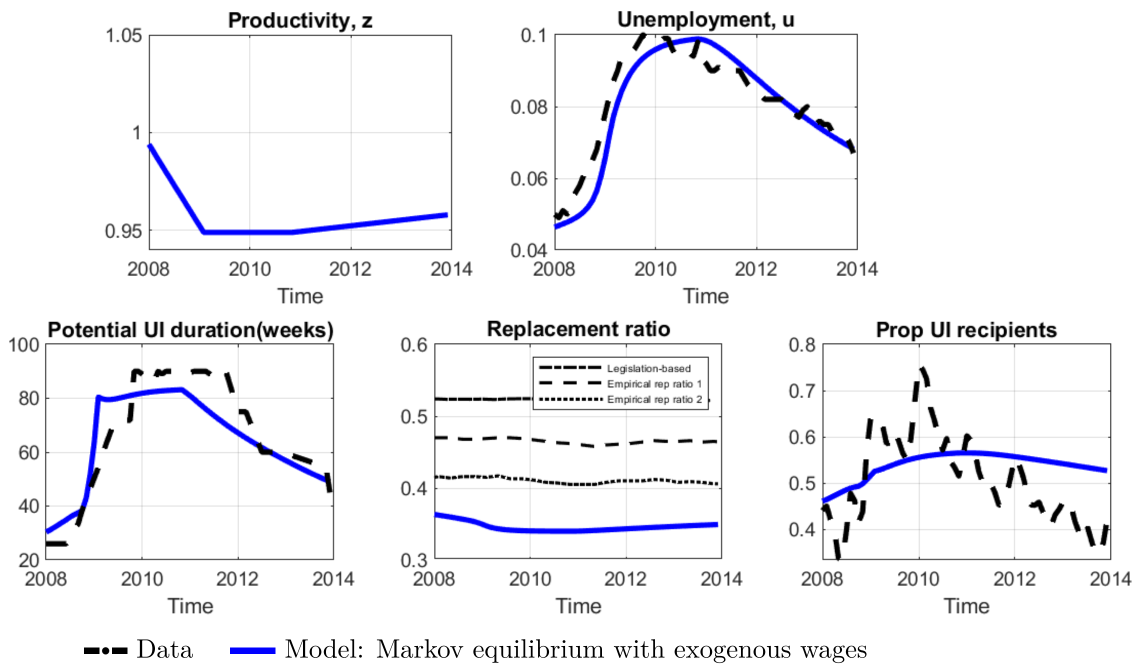
Figure 6: Economies under different policy regimes in the Great Recession: Markov vs Acyclical vs Ramsey policy.



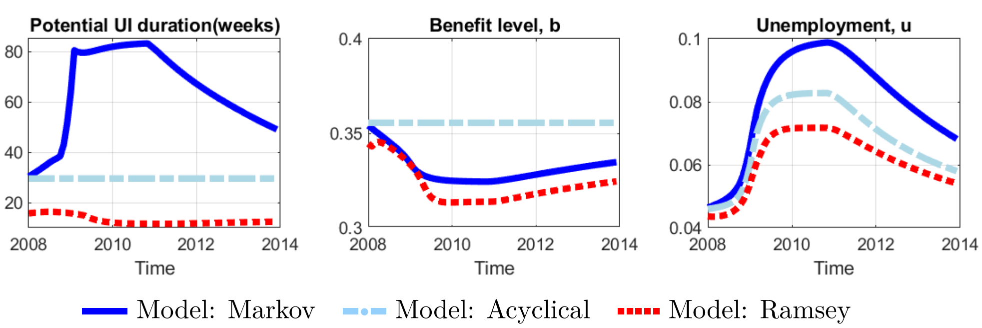
Note: Each economy is simulated with the same initial steady state in 2007 Dec (the steady state of the Markov equilibrium). The shock follows the path of productivity in Figure 5. Potential UI duration (in weeks) is calculated as $1/(1-d) \times 4$. The proportion of UI recipients among unemployed workers is computed as $u^1 d/u$. The average search is computed as $s^1 \times u^1 d/u + s^0 \times (1 - u^1 d/u)$.

Figure 7: Simulation of Model with Exogenous Wages in the Great Recession.

Panel A: Shock and model fit of Markov economy.



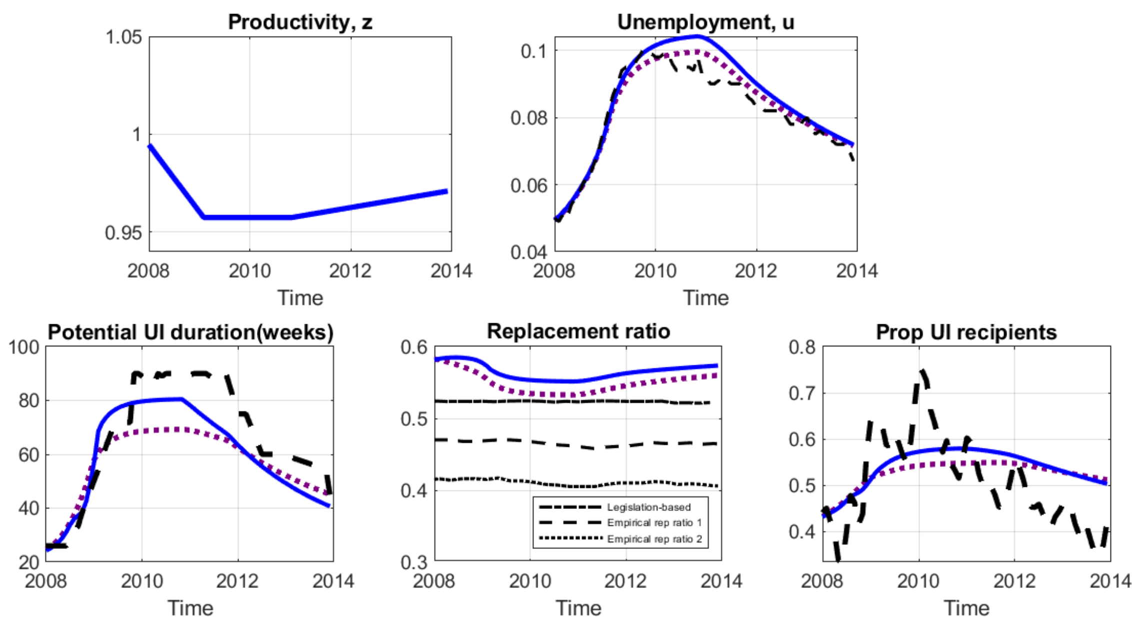
Panel B: Comparison of different UI policies.



Note: Exogenous wages follow the wage function $w(z) = \bar{w}z^{\epsilon_w}$. Variables are constructed in the same ways as in Figures 5 and 6.

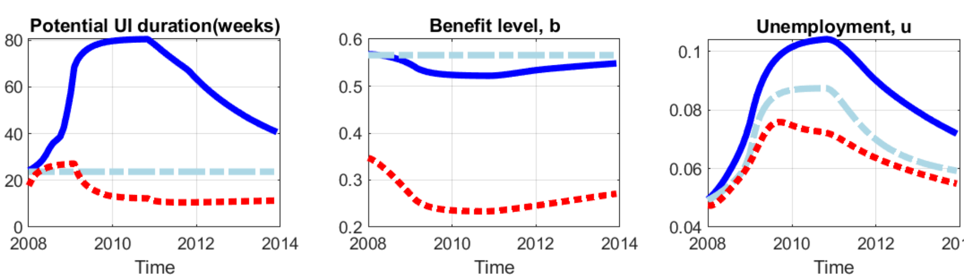
Figure 8: Simulation of Model with Unbalanced Government Budget in the Great Recession.

Panel A: Comparison of model with baseline.



Data   Baseline Markov equilibrium   Markov equilibrium with unbalanced government budget

Panel B: Comparison of different UI policies under unbalanced government budget.



Model: Markov   Model: Acyclical   Model Ramsey

Note: Unbalanced government budget is modeled using a cyclical wedge in the marginal effects of UI policy on tax to create lower tax cost of UI benefits during recessions: $\hat{\tau}_b = \partial\tau/\partial b + \epsilon_b(z - \bar{z})$ and $\hat{\tau}_d = \partial\tau/\partial_d + \epsilon_d(z - \bar{z})$. This exercise uses $\epsilon_b = 0.01$ and $\epsilon_d = 0.01$. All other parameters including productivity path are kept the same as the baseline. Variables are constructed in the same ways as in Figures 5 and 6.