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Unemployment insurance and labour productivity over the business cycle ☆

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ABSTRACT

This paper quantifies the effects of the increasing maximum unemployment insurance (UI) duration during recessions on the drop in the correlation between output and labour productivity in the U.S. since the early 1980s – the so-called productivity puzzle. Using a general equilibrium search and matching model with stochastic UI duration, heterogeneous match quality, variable search intensity and on-the-job search, I demonstrate that the model can explain over 40 percent of the drop in this correlation (28 percent when the Great Moderation is taken into account). More generous UI extensions during recent recessions cause workers to be more selective with job offers and lower job search effort. The former channel raises the overall productivity in bad times. The latter prolongs UI extensions since in the U.S. they are triggered by high unemployment.

1. Introduction/motivation

The labour productivity has become significantly less procyclical in the U.S. since the early 1980s. In particular, the cross correlation between output and labour productivity has fallen from 0.70 in the 1948-1985 period to only around 0.30 thereafter as depicted in Fig. 1. This change in the procyclicality of the labour productivity is usually coined "the labour productivity puzzle". Moreover, it can be observed that the fall in the correlation between output and labour productivity mostly happened right after recessionary periods since the 1980s as depicted in Fig. 2.

This paper explores the hypothesis that the fall in the procyclicality of labour productivity is related to the systematic change in the generosity of the U.S. unemployment insurance (UI) system. One distinctive feature of its UI system is the extension of the maximum UI duration that is triggered when the unemployment rate is above a certain threshold making the policy countercyclical. While the standard UI duration is 26 weeks, the extended UI duration has increased from the average of 52 weeks during 1948-1985 to 78 weeks after 1985. Fig. 3 summarises this increasing generosity of the UI duration policy in the U.S.

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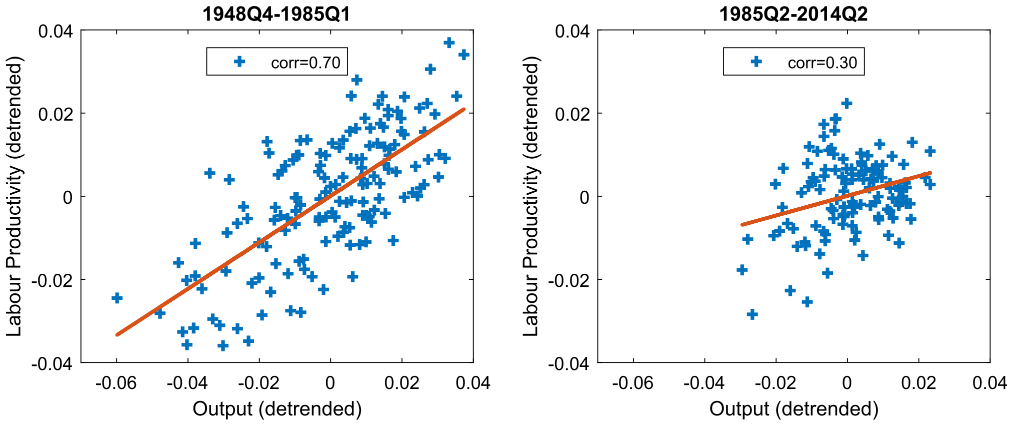

Fig. 1. Correlations between output and output per worker for 1948Q1-1985Q1 and 1985Q2-2014Q2 (both variables are of quarterly frequency and detrended using the HP filter with a smoothing parameter of 1,600) (solid lines are linear fitted trends) (Source: BEA and BLS).

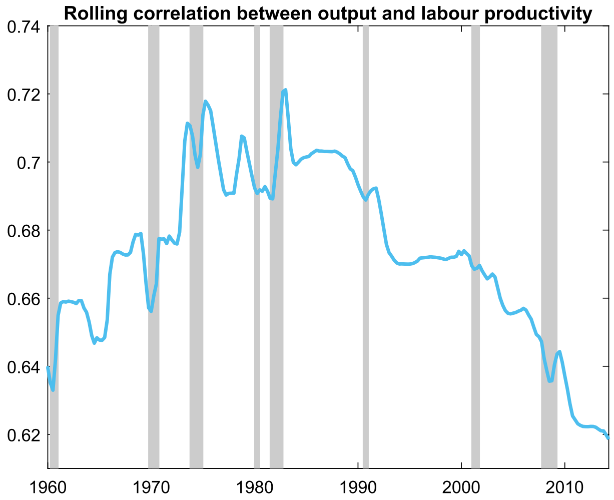

Fig. 2. Rolling correlation coefficients between output and output per worker from 1948Q1 (up until 2014Q2) (both variables are of quarterly frequency and detrended using the HP filter with a smoothing parameter of 1,600) (shaded areas denote recessions) (Source: BEA and BLS).

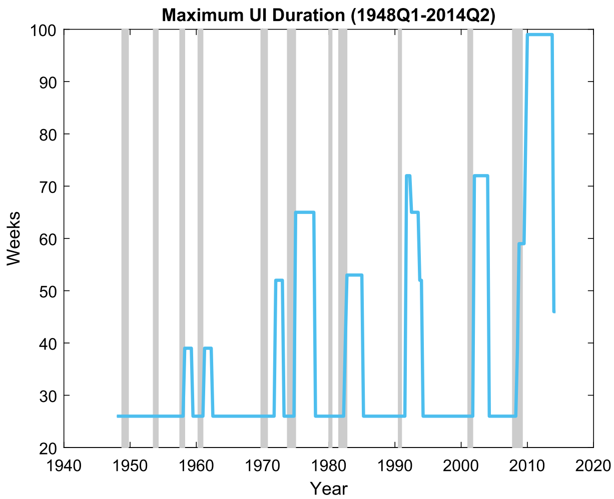

Fig. 3. Maximum UI duration (in weeks) as plotted as against time periods from 1948Q1 to 2014Q2 (shaded areas denote recessions) (Source: ETA).

This increase in the generosity of the maximum UI duration during the times of high unemployment, often associated with recessions, could weaken the links between output and output per worker via two channels. First, UI extensions raise the workers' outside option, making them more selective with respect to the quality of job offers; as a result, unproductive worker-firm matches are less likely to survive. This helps create an upward pressure on labour productivity during recessions. Second, UI extensions lower job search effort of the (insured) unemployed causing a slower worker-job matching and more persistent unemployment which further prolongs the extensions themselves. It is clear that the first channel has a positive effect on labour productivity during recessions as low quality matches are either destroyed or not formed. However, the second channel has an ambiguous effect on labour productivity since UI extensions lower both output (bringing down productivity) and the number of employed workers (increasing average productivity). It depends on the strengths of these channels whether UI extensions would bring down the correlation between output and output per worker during recessions, and, after calibrating to the U.S. economy, this turns out to be the case. The increase in the generosity of UI extensions in the post-1985 period implies that the UI effect on the labour productivity is expected to be stronger in recent recessions than in earlier ones. This contributes to the fall in the procyclicality of labour productivity.

I extend the Mortensen-Pissarides general equilibrium search and matching model to incorporate stochastic UI duration, heterogeneous match quality, variable search intensity and on-the-job search. To my knowledge, this paper is the first to realistically incorporate the feature where UI extensions are a function of the unemployment rate which is the case in the U.S.. The cyclical behaviour of the average match quality is vital in explaining the correlation between output and output per worker in the model. By allowing for variable search intensity, I can separately identify the contributions of the two proposed channels, namely, match formation and job search effort, on the fluctuations in the labour productivity over the business cycle. Lastly, searching on the job is allowed so that the model produces a realistic correlation between unemployment and vacancies.

I find that the countercyclical UI policy can account for 43 percent of the drop in the contemporaneous correlation between output and labour productivity observed in the U.S. In a decomposition exercise, I find that the responses of match formations/separations and job search effort to UI extensions have a significant explanatory power over the correlation between output and labour productivity. Each of the two channels can explain around half of the correlation drop that the model can produce. I find that the responses of firms' vacancy creation to UI extensions are also important but to a lesser extent as they account for around one-fifth of the correlation drop generated by the model. The model also generates realistic moments of key labour market variables in the U.S., including the share of insured unemployed workers over the business cycle.

As a robustness check, I extend to the model to take into account the Great Moderation, the phenomenon where there is a reduction in the macroeconomic volatility also starting around the mid 1980s. The decreased volatility does reduce the impact of the generous UI extensions because it implies less extreme negative shocks that can trigger UI extensions; however, the overall UI effect is still significant and explains around 28 percent of the drop in the procyclicality of the labour productivity. Lastly, I show that the model generates the downward-sloping duration-dependent job finding probability, qualitatively similar to the data, even though unemployment duration is not modelled explicitly. Different job finding rates amongst the unemployed imply that those with a higher rate (the uninsured unemployed) exit unemployment faster and those with a lower rate (the insured unemployed) have longer unemployment duration. The aggregate job finding probability hence falls with unemployment duration.

I am not the first to investigate the source of the decline in the correlation between output and labour productivity. Galí and van Rens (2014) suggest that decreasing employment adjustment costs have generated a substantial fall in the procyclicality of the labour productivity. Berger (2018) explains the puzzle using a quantitative model with the countercyclical restructuring of firms where lower-quality workers are more likely to be shed during recessions, and this occurs more often in recent times due to the decreasing labour union power. Garin et al. (2016) use a model with aggregate and island-specific shocks as well as complete markets, and show that the falling correlation between output and labour productivity is from the relatively lower importance of aggregate shocks. McGrattan and Prescott (2012) also study the sources of the labour productivity puzzle by considering intangible capital and sectoral productivity shocks. The source of the labour productivity puzzle in this paper, namely, UI extensions, can be directly verified from the data, and this hypothesis is also supported by existing literature on UI extensions.

There are a number of studies showing significant effects of changes in the UI policy on macroeconomic variables including the labour productivity, wages and unemployment. From a theoretical perspective, Acemoglu and Shimer (2000) show that an increase in both the duration and the level of UI benefits can increase labour productivity and wages in a model with risk aversion and precautionary savings. Marimon and Zilibotti (1999), using a search and matching model with risk-neutral agents and two-sided heterogeneity, show that a positive replacement rate with unlimited UI duration also leads to a higher labour productivity when compared to the case without UI. This paper extends from Acemoglu and Shimer (2000) and Marimon and Zilibotti (1999) by allowing for stochastic aggregate productivity so that the business cycle properties of the model, particularly the co-movement between labour productivity and output, can be studied. Furthermore, there are empirical results that support the hypothesis in this paper. Findings from Ehrenberg and Oaxaca (1976) suggest that a higher UI benefit level has a positive impact on re-employment wages. Caliendo et al. (2013) find that a longer UI duration increases re-employment wages, match quality and match stability.

It is useful to compare the model in this paper, particularly the UI duration policy, with that in Mitman and Rabinovich (2014) who study the effects of maximum UI duration in the U.S. on jobless recoveries,[1] and Faig et al. (2012) who study the contribution of countercyclical UI duration policy on the labour market dynamics. Mitman and Rabinovich (2014) assume all UI extensions are unexpected and perceived to last forever by the agents. Although the model in this paper may not be able to replicate exactly the timing of UI extensions like in theirs, it can match quite well most of the characteristics in the labour markets usually associated with the UI duration policy whilst preserving the agents' rational expectation. I assume the UI duration policy varies with the unemployment rate instead of the aggregate total factor productivity like in Faig et al. (2012). Whilst this offers a more accurate length of UI extensions (since unemployment tends to be more persistent than does the total factor productivity), the model is computationally more difficult to solve since the entire distribution of workers by employment status and heterogeneous match quality becomes a state variable. I provide an algorithm that solves the model and delivers results with high accuracy.

Lastly, Hagedorn et al. (2013) empirically investigate the macroeconomic impact of UI extensions using U.S. county-level data by exploiting the variations in UI duration policies of bordering counties belonging to different states. Whilst they focus on the UI effect on vacancy creation and do not consider endogenous search intensity per se, they explore the search channel that comes from mobility decisions and find it to have a negligible role.[2] This paper complements the study by constructing and calibrating a search and matching model to study the responses of match formations/separations, job search intensity and vacancy creation to UI extensions.

The paper is organised as follows: Section 2 describes the model. Section 3 discusses the calibration exercise. Section 4 analyses the results. Section 5 concludes.

2. Model

2.1. Setup

The model is based on Mortensen and Pissarides (1994)'s general equilibrium search and matching model with the incorporation of aggregate productivity shocks, stochastic UI duration, heterogeneous match quality, variable search intensity and on-the-job search. Time is discrete and of monthly frequency. Search is assumed to be random. There is a continuum of workers of measure one and a larger continuum of firms each with either zero or one employee. They are infinitely-lived and risk-neutral, and they discount future utility flows or profits each period by a constant factor $\beta \in (0, 1)$.

2.1.1. Production

Production function. The production technology of a worker-firm match in period t with match quality m is $y_{m,t} = z_t \times m$, where $y_{m,t}$ is the output the match produces, and z_t is the total factor productivity (TFP). The price of $y_{m,t}$ is normalised to unity.

Match quality. By assumption, variations in the labour productivity in this model only come from the changes in the average match quality given the aggregate state. This match-specific productivity drawn at the start of any worker-firm relationship is distributed according to a Beta distribution with parameters $\{\beta_1, \beta_2\}$. The distribution function is $F(m) = \underline{m} + \text{Betacdf}(m - \underline{m}, \beta_1, \beta_2)$ where $\underline{m} > 0$ is the lowest productivity level, and $1 + \underline{m}$ is the highest. Each match-specific productivity m will remain until the match is either destroyed (with probability δ) or hit by a shock that causes the match to redraw m from $F(m)$ (with probability λ) in each period.

Aggregate productivity shocks. There is only one exogenous aggregate shock in the model which is the shock to the total factor productivity, z, whose natural logarithm has an AR(1) representation with ρ_z being its AR parameter. Specifically, $\ln z_t = \rho_z \ln z_{t-1} + \varepsilon_t$ where ε_t is normally and independently distributed with mean zero and standard deviation $\sigma_z > 0, \forall t$.

2.1.2. Workers

Workers maximise the expected discounted lifetime utility: $E_0 \sum_{t=0}^{\infty} \beta^t \left[c_t - \nu(s_t)\right]$ where $E_t(\cdot)$ is the expectation operator conditional on period-t information, c_t is consumption and $\nu(\cdot)$ is the disutility of job search effort s_t which can be exerted during both unemployment and employment. Workers can be in one of the three states: employed (e), unemployed with UI (u^{UI}), and unemployed without UI (u^{UU}).

An employed worker in period t with match-specific quality m works and receives wage $w_{m,t}$ from her matched firm. She searches on the job with intensity $s^e_{m,t}$ that costs disutility of $\nu_e(s^e_{m,t}) = a_e \cdot (s^e_{m,t})^{1+d_e}$ where a_e and d_e are positive constants. At the end of the period: (i) her current match is exogenously destroyed with probability δ in which case she becomes unemployed immediately, (ii) her match-specific productivity for $t+1$ is redrawn from a time-invariant distribution $F(m)$ with probability λ, (iii) she meets a vacant firm with probability $p(s^e_{m,t}) \equiv p^e_{m,t}$, draws a new match quality m and

[1] In Mitman and Rabinovich (2015), they also study the optimal UI policy where unemployed workers can vary their job search intensity. Since matches in this paper differ by match qualities, I also allow for on-the-job search.

[2] Hagedorn et al. (2013) suggest that a small role of job search behaviour may be due to small variations in maximum UI durations across bordering counties which may not justify mobility decisions.

decides whether to stay with her current firm, and (iv) the wage is renegotiated for the production next period. If becoming unemployed in $t+1$, an employed worker in period t is eligible for UI benefits in period $t+1$ with probability $(1-\psi) \in (0, 1]$ reflecting how some newly unemployed workers are ineligible for or do not claim UI benefits.[3] The employed can always exit employment if desired at the end of period t.

The aggregate states variables in this economy are $\{z, u, u^{UI}, u^{UU}, e_m; \forall m\}$. Respectively, they are the total factor productivity, the unemployment rate, the insured unemployment rate, the uninsured unemployment rate and the measure of employed workers at each match quality. I let ω denote this set of state variables. Given the recursive nature, the time subscripts are dropped and variables with superscript $'$ are of the next period. Variables with subscripts m and/or ω depend on the match quality and/or the set of aggregate state variables. $E_{\omega'|\omega}[\cdot]$ is the mathematical expectation operator over the distribution of $\omega'|\omega$. $E_m[\cdot]$ is similarly defined but taken over the invariant distribution of m, $F(m)$.

Given ω, an employed worker with match quality m and last period's employment status $j \in \{e, UI, UU\}$ has the following value function:

$$
\begin{aligned}
W^j(m;\omega) = \max_{s^e(m;\omega)} \underbrace{w^j(m;\omega)}_{\text{wage}} - \underbrace{\nu_e(s^e(m;\omega))}_{\substack{\text{disutility from}\\ \text{job search}}} + \beta E_{\omega'|\omega}\Bigg[\dots \\
&\underbrace{(1-\delta)(1-\lambda)}_{\substack{\Pr(\text{match survives,}\\ \text{same } m)}} \Big(\underbrace{(1-p^e(m;\omega)(1-F(m)))}_{\Pr(\text{no job-to-job transition})} W^{e+}(m;\omega') \\
&+ \underbrace{p^e(m;\omega)(1-F(m))}_{\Pr(\text{make job-to-job transition})} \; E_{m'|m'>m}[W^{e+}(m';\omega')] \Big) \\
&+ \underbrace{(1-\delta)\lambda}_{\substack{\Pr(\text{match survives,}\\ \text{changing } m)}} \; E_{m'}\Big[\underbrace{(1-p^e(m;\omega)(1-F(m')))}_{\Pr(\text{no job-to-job transition})} W^{e+}(m';\omega') \\
&+ \underbrace{p^e(m;\omega)(1-F(m'))}_{\Pr(\text{make job-to-job transition})} \; E_{m''|m''>m'}[W^{e+}(m'';\omega')] \Big] \\
&+ \underbrace{\delta}_{\substack{\Pr(\text{match}\\ \text{destroyed})}} \Big((1-\psi)U^{UI}(\omega') + \psi U^{UU}(\omega') \Big) \Bigg]
\end{aligned} \tag{1}
$$

where $W^{e+}(m;\omega') \equiv \max\{W^e(m;\omega'), (1-\psi)U^{UI}(\omega') + \psi U^{UU}(\omega')\}$ showing that, conditional on the match not being exogenously destroyed, an employed worker can choose to either remain employed in the next period and receive the value $W^e(\cdot;\cdot)$[4] or return to unemployment and risk not having UI benefits (which occurs at rate ψ). Last period's employment status $j \in \{e, UI, UU\}$ matters for the workers as it represents the outside option they have when negotiating for wages. $U^{UI}(\omega)$ and $U^{UU}(\omega)$ are the values of being insured and uninsured unemployed respectively. $p^e(m;\omega)$ is the probability that an employed worker whose current match quality is m meets a vacant firm which depends on her search intensity $s^e(m;\omega)$. δ and λ are respectively the match destruction probability and the probability that the match redraws its match quality. The expression for the optimal search intensity for employed workers can be found in Appendix B.

An insured unemployed worker in period t receives UI benefits b and leisure flow h.[5] She also exerts job search effort s_t^{UI} that comes with a disutility cost of $\nu_u(s_t^{UI}) = a_u \cdot (s_t^{UI})^{1+d_u}$ where a_u and d_u are positive constants. She meets a vacant firm with probability $p(s_t^{UI}) \equiv p_t^{UI}$. A new worker-firm match draws a match-specific productivity for their production in $t+1$ from the time-invariant distribution $F(m)$. They can dissolve the match and return to the unemployment/vacancy pool if the draw is not good enough. An insured unemployed worker in t who fails to be employed in $t+1$ loses her UI eligibility in $t+1$ with probability $\phi(u_t)$ where u_t is the unemployment rate at the beginning of t. Since the inverse of $\phi(u_t)$ is the expected duration of being able to receive UI, I use this function to control for the maximum UI duration that changes with the unemployment rate (as in the case in the U.S.). The properties of $\phi(u_t)$ will be discussed in more detail in the next

3 In the U.S., the average ratio of the insured unemployed to the total unemployed is 36% between 1967-2014. The remaining 64% is a combination of those ineligible for UI, those who exhausted their UI and those not taking up UI. Each state sets its own UI eligibility standards. A general rule is that the worker must be out of work through no fault of his/her own; however, rules such as minimum earnings and employment duration prior to unemployment as well as justified causes in case of voluntary separations (quits) vary across states. Auray et al. (2019) find that the average UI take-up rate is 77% between 1989-2012.

4 The value $W^e(\cdot;\cdot)$ for the next period can vary depending on whether the worker-firm match has to redraw its match quality and whether the worker makes a job-to-job transition.

5 This flow h can be interpreted as the value of leisure, home production, food stamps, etc.

subsection.[6] Insured unemployed workers that meet a firm but decide to remain unemployed and continue to search for a job may additionally lose UI eligibility with probability ξ.[7] This parameter can be greater than zero to reflect the job search monitoring in UI recipients.[8]

For an uninsured unemployed worker, the setting is analogous except she does not receive the UI benefits b and when failing to become employed she simply remains unemployed without UI. She also exerts job search effort s_t^{UU} that comes at the utility cost of $\nu_u(s_t^{UU}) = a_u(s_t^{UU})^{1+d_u}$, and she meets a vacant firm with probability $p(s_t^{UU}) \equiv p_t^{UU}$. The Bellman equations for the insured and uninsured unemployed workers can be written as, respectively:

$$\begin{aligned} U^{UI}(\omega) = \max_{s^{UI}(\omega)} \; & b + h - \underbrace{\nu_u(s^{UI}(\omega))}_{\substack{\text{disutility from}\\ \text{job search}}} + \beta \underbrace{p^{UI}(\omega)}_{\substack{\text{Pr(meeting}\\ \text{a firm)}}} E_{m'\omega'|\omega}\Big[\max\Big\{ W^{UI}(m';\omega'), \\ & \underbrace{(1-\phi(u))(1-\xi)}_{\substack{\text{Pr(UI eligible | turn}\\ \text{down a firm)}}} U^{UI}(\omega') + \underbrace{\Big(\phi(u) + (1-\phi(u))\xi\Big)}_{\substack{\text{Pr(UI ineligible | turn}\\ \text{down a firm)}}} U^{UU}(\omega') \Big\}\Big] \\ & + \beta \underbrace{(1-p^{UI}(\omega))}_{\text{Pr(not meeting a firm)}} E_{\omega'|\omega}\Big[\underbrace{(1-\phi(u))}_{\substack{\text{Pr(UI eligible |}\\ \text{no meeting)}}} U^{UI}(\omega') + \underbrace{\phi(u)}_{\substack{\text{Pr(UI ineligible |}\\ \text{no meeting)}}} U^{UU}(\omega') \Big] \end{aligned} \tag{2}$$

$$\begin{aligned} U^{UU}(\omega) = \max_{s^{UU}(\omega)} \; & h - \underbrace{\nu_u(s^{UU}(\omega))}_{\substack{\text{disutility from}\\ \text{job search}}} \\ & + \beta \underbrace{p^{UU}(\omega)}_{\text{Pr(meeting a firm)}} E_{m'\omega'|\omega}\Big[\max\Big\{ W^{UU}(m';\omega'), U^{UU}(\omega') \Big\}\Big] \\ & + \beta \underbrace{(1-p^{UU}(\omega))}_{\text{Pr(not meeting a firm)}} E_{\omega'|\omega}[U^{UU}(\omega')] \end{aligned} \tag{3}$$

where $p^{UI}(\omega)$ is the probability that an insured unemployed worker meets a vacant firm which depends on her search intensity $s^{UI}(\omega)$, and $p^{UU}(\omega)$ is analogously defined. We can see from equation (2) that, for insured unemployed workers, the outside option for those meeting a vacant firm is smaller than for those not meeting a vacant firm, i.e. $(1-\phi(u))(1-\xi) < \phi(u)$ and $U^{UI}(\omega) > U^{UU}(\omega)$. This is due to the possibility of being UI ineligible after turning down a job offer. Note that if the UI exhaustion rate becomes unity, i.e. no one is insured unemployed, there will be no difference between equations (2) and (3). The expressions for the optimal search intensities for insured and uninsured unemployed workers can be found in Appendix B.

2.1.3. UI duration policy: $\phi(u_t)$

Empirically, there are three main categories of UI duration policy in the U.S.: (i) the standard UI duration of 26 weeks, (ii) the automatic extension programme that is triggered by the state unemployment rate (either total, insured or both) called "Extended Benefits (EB)" programme which extends UI further by 13-20 weeks, and (iii) the ad-hoc programmes that are often issued in the recessions and also triggered by the state unemployment rate providing additional UI ranging from 13 to 53 weeks. To capture these features, I combine the extensions in (ii) and (iii) together and make them a function of the unemployment rate u.[9] Specifically, $\phi(u)$ can take one of the two values: a low value which implies a longer UI duration for the recessionary episodes and a high value for the normal time. There is a threshold unemployment rate $\bar{u}$ such that whenever $u \geq \bar{u}$, the maximum UI duration increases, and $\phi(u)$ takes the low value ϕ_L, and whenever $u < \bar{u}$, the maximum UI duration remains standard at 26 weeks, and $\phi(u)$ takes the high value ϕ_H where $0 < \phi_L < \phi_H < 1$. In summary,

$$\phi(u_t) = \phi_L \mathbb{1}\{u_t \geq \bar{u}\} + \phi_H \mathbb{1}\{u_t < \bar{u}\}; \; \forall t$$

[6] This setting for the UI duration policy, first used in Fredriksson and Holmlund (2001), helps reduce the state space greatly.

[7] The effective probability of an insured unemployed worker being eligible for UI next period given she turns down a match formation is therefore $(1-\phi(u_t))(1-\xi)$.

[8] In the U.S., UI recipients must look for and be ready to accept "suitable work". If they are offered a job that pays at least the UI cutoff wage (10% below the prevailing wage) for jobs in their most recent occupation, they must accept it or risk losing UI benefits. However, as UI monitoring is done mainly via work-search activity books and meetings with local career centres, it can be imperfect.

[9] This is the reason why the unemployment rate is a state variable for the policy functions and so is the composition of employed and unemployed workers due to the endogenous destruction margin.

I assume this UI duration policy $\phi(u)$ is known to all agents; therefore, they expect a longer UI duration when the unemployment rate is expected to exceed $\bar{u}$.[10] That is, agents have a rational expectation about the timings of UI extensions. In order to finance UI benefits, the government collects lump sum tax τ_t from all firms that are in production. The tax is set to satisfy the government budget constraint in each period. Namely,

$$\tau_t = \frac{bu_t^{UI}}{1-u_t};\ \forall t$$

2.1.4. Firms

Firms maximise the expected discounted profits. They are matched with either one or zero worker. A firm in operation (matched with a worker) in period t sells output $y_{m,t}$, pays wage $w_{m,t}$ to the worker and pays lump sum tax τ_t. Analogous to an employed worker, it faces an exogenous match-destruction shock and a shock to redraw its match-specific productivity (at rate δ and λ respectively). Further, it becomes unmatched when its worker takes up a new job offer.[11] The producing firm can walk away from the match if desired at the end of period. An unmatched firm posts a vacancy to attract job searchers.

Let J^j denote the value of a filled job given its worker's employment status last period $j \in \{e, UI, UU\}$, and V the value of posting a vacancy. The Bellman equation for an operating firm is

$$\begin{aligned} J^j(m;\omega) = {} & y(m;\omega) - w^j(m;\omega) - \tau(\omega) + \beta E_{\omega'|\omega}\Bigg[\\ & \underbrace{(1-\delta)(1-\lambda)}_{\substack{\text{Pr(match survives,}\\ \text{same } m)}} \Big(\underbrace{(1-p^e(m;\omega)(1-F(m)))}_{\text{Pr(no job-to-job transition)}} J^{e+}(m;\omega') \Big) \\ & + \underbrace{(1-\delta)\lambda}_{\substack{\text{Pr(match survives,}\\ \text{changing } m)}} E_{m'}\Big[\underbrace{(1-p^e(m;\omega)(1-F(m')))}_{\text{Pr(no job-to-job transition)}} J^{e+}(m';\omega') \Big] + \delta V(\omega') \Bigg] \end{aligned} \tag{4}$$

where $J^{e+}(m;\omega') \equiv \max\{J^e(m;\omega'), V(\omega')\}$ showing that a firm can freely choose to either remain with its current worker and receive $J^e(m;\omega')$ or become unmatched and receive $V(\omega')$ in the next period.

A vacant firm pays a flow cost of κ each period to post a vacancy. It meets a worker with probability q_t, and together they draw a match-specific productivity for $t+1$ and decide whether to continue with the production. It cannot directly choose the type(s) of workers to meet and therefore needs to take into account the distribution of workers over the employment status and, if employed, match-specific productivity as well as their search effort. I assume that the free entry condition holds which means that the value of a vacant firm is always zero, i.e. $V(\omega) = 0, \forall \omega$. The value of posting a vacancy is

$$\begin{aligned} V(\omega) = {} & -\kappa + \beta \underbrace{q(\omega)}_{\substack{\text{Pr(meeting}\\ \text{a worker)}}} E_{\omega'|\omega}\Bigg[\sum_m \underbrace{\zeta^e(m;\omega)(1-F(m))}_{\substack{\text{Pr(meeting an employed}\\ \text{worker with } m \text{ willing to}\\ \text{move} \mid \text{meeting occurs)}}} E_{m'|m'>m}[J^{e+}(m';\omega')] \\ & + \underbrace{\zeta^{UI}(\omega)}_{\substack{\text{Pr(meeting an insured}\\ \text{unemployed worker} \mid\\ \text{meeting occurs)}}} E_{m'}[J^{UI+}(m';\omega')] + \underbrace{\zeta^{UU}(\omega)}_{\substack{\text{Pr(meeting an uninsured}\\ \text{unemployed worker} \mid\\ \text{meeting occurs)}}} E_{m'}[J^{UU+}(m';\omega')] \Bigg] \end{aligned} \tag{5}$$

where ζ's represent the probability that a vacant firm meets a certain type of worker by employment status and, if the worker is currently employed, match quality given that a worker-firm meeting takes place. Particularly,

$$\zeta^e(m) = \frac{(1-\lambda)s_m^e e_m + \lambda f(m) s^e e}{s^e e + s^{UI}u^{UI} + s^{UU}u^{UU}};\quad s^e e = \sum_m s_m^e e_m$$

$$\zeta^{UI} = \frac{s^{UI}u^{UI}}{s^e e + s^{UI}u^{UI} + s^{UU}u^{UU}};\quad \zeta^{UU} = \frac{s^{UU}u^{UU}}{s^e e + s^{UI}u^{UI} + s^{UU}u^{UU}}$$

and $J^{j+}(m;\omega') \equiv \max\{J^j(m;\omega'), V(\omega')\}$ for $j \in \{e, UI, UU\}$.

[10] As explained in Appendix A, some UI extensions are not anticipated per se but due to the fact that the U.S. government has always issued ad-hoc UI extensions during the recessions, it can be argued that in reality agents expect these additional ad-hoc UI extensions *around* recessionary periods (particularly with a high unemployment rate), just not exactly when the policy is implemented.

[11] The probability that this event happens depends on the match-specific productivity they will have at the start of next period.

2.1.5. Meeting function

The meeting function $M(s_t, v_t)$ takes the aggregate search intensity s_t and the number of job vacancies v_t in period t as inputs and gives a number of meetings between workers and firms as output.[12] The function has constant returns to scale, and it is increasing and concave in its arguments. In particular, I assume[13]:

$$M(s_t, v_t) = \frac{s_t v_t}{\left(s_t^l + v_t^l\right)^{\frac{1}{l}}}$$

Let $\theta_t = v_t/s_t$ denote the market tightness. The worker's meeting rate per search unit is $M(s_t, v_t)/s_t = M(1, \theta_t)$ which I also call the conditional job finding rate per search unit since a positive match surplus is required for a job to be created. The conditional job finding rate for an unemployed worker of type $i \in \{UI, UU\}$ is thus $s_t^i M(1, \theta_t) = p_t^i$. Analogously, it is $s_{m,t}^e M(1, \theta_t) = p_{m,t}^e$ for an employed worker with match quality m. The conditional job filling rate for a vacant firm is $M(s_t, v_t)/v_t = M(1/\theta_t, 1) = q_t$.

2.2. Wage and match surplus

Wages are negotiated at the end of each period after the match quality for the next period is realised. They are determined using a generalised Nash bargaining rule. The bargaining power of a worker is $\mu \in (0, 1)$ and that of a firm is $1 - \mu$. Given the match quality and the aggregate state variables $(m; \omega)$, the generalised Nash bargaining rule implies three different wages depending on the worker's employment status last period $j \in \{e, UI, UU\}$ due to their different outside options. Namely,

$$w^j(m; \omega) = \text{argmax} \left(WS^j(m; \omega)\right)^{\mu} \left(J^j(m; \omega)\right)^{(1-\mu)} \tag{6}$$

where WS^j is the surplus from working for type-j employed workers which are as follows:

$$\begin{aligned}
WS^e(m; \omega) &= W^e(m; \omega) - (1-\psi)U^{UI}(\omega) - \psi U^{UU}(\omega) \\
WS^{UI}(m; \omega) &= W^{UI}(m; \omega) - (1-\phi(u))(1-\xi)U^{UI}(\omega) - (\phi(u) + (1-\phi(u))\xi)U^{UU}(\omega) \\
WS^{UU}(m; \omega) &= W^{UU}(m; \omega) - U^{UU}(\omega)
\end{aligned}$$

We can see from here that workers with different status j have different outside options because they face different probabilities of being able to receive UI in case they walk away from the negotiation.[14] Further, the total match surplus (or joint surplus) of a worker-firm match given the worker's previous employment status $j \in \{e, UI, UU\}$ can be defined as

$$S^j(m; \omega) = WS^j(m; \omega) + J^j(m; \omega)$$

The firm's surplus from being matched with a worker is simply the value of being matched with a worker (J) itself because of the free entry condition. The expressions for these employment-history-dependent surpluses can be found in Appendix B. With the Nash bargaining rule, we have $WS^j(m; \omega) = \mu S^j(m; \omega)$ and $J^j(m; \omega) = (1-\mu)S^j(m; \omega)$. Therefore, both the worker and the firm always agree it is profitable to form a match if and only if their total match surplus is positive, i.e. $S^j(m; \omega) > 0$.

2.3. Transitions

Employment. The mass of employed workers in t with match quality m, namely $e_{m,t}$, evolves as follows

$$\begin{aligned}
e_{m,t+1} = \Bigg(& (1-\delta) \underbrace{(1-\lambda)(1 - p_{m,t}^e + p_{m,t}^e F(m))}_{\text{no shock to } m \text{, no job-to-job transition}} e_{m,t} + \underbrace{(1-\delta)(1-\lambda) f(m) \sum_{m'<m} p_{m',t}^e e_{m',t}}_{\substack{\text{no shock to } m' \text{ but} \\ \text{job-to-job transit to } m}} \\
& + (1-\delta) \underbrace{\lambda f(m) \sum_{m'} (1 - p_{m',t}^e + p_{m',t}^e F(m)) e_{m',t}}_{m' \text{ changes to } m \text{, no job-to-job transition}} + (1-\delta) \underbrace{\lambda F(m) f(m) \sum_{m'} p_{m',t}^e e_{m',t}}_{\substack{m' \text{ changes to any match} \\ \text{quality below } m \text{ but} \\ \text{job-to-job transit to } m}} \Bigg) \mathbb{1}\{S_{m,t+1}^e > 0\}
\end{aligned}$$

[12] s_t is the sum of aggregate search intensity of employed and unemployed workers in time t.

[13] This matching function is similar to the one introduced by den Haan et al. (2000) with an addition of the variable search intensity.

[14] Note that, for employed workers, I assume that their outside option is to return to unemployment and not to stay in the current match. This assumption is made for simplicity as otherwise the entire history of match qualities of an employed worker will become a state variable.

$$+f(m)(u_t^{UI} p_t^{UI})\mathbb{1}\{S_{m,t+1}^{UI} > 0\} + f(m)(u_t^{UU} p_t^{UU})\mathbb{1}\{S_{m,t+1}^{UU} > 0\} \tag{7}$$

where $\mathbb{1}\{\cdot\}$ is an indicator function.[15] The first term on the right hand side $((\ldots)\mathbb{1}\{S_{m,t+1}^{e} > 0\})$ accounts for all employed workers with different match qualities in t ending up with match quality m in $t+1$. The last two terms represent, respectively, insured and uninsured unemployed workers in t who become employed with match quality m in $t+1$. Total employment is the sum of all employed workers over the match qualities $e_t = \sum_m e_{m,t}$, and the aggregate output can be computed as $y_t = z_t \sum_m m \cdot e_{m,t}$.

Unemployment. Unemployed workers with and without UI benefits and total unemployment evolve respectively as follows

$$u_{t+1}^{UI} = \underbrace{(1-\phi_t)(1-p_t^{UI})}_{\text{no meeting, not losing UI}} u_t^{UI} + \underbrace{\chi_t^{UI}(1-\phi_t)(1-\xi)p_t^{UI}}_{\text{turning down a firm, not losing UI}} u_t^{UI} + \underbrace{(1-\psi)\rho_{x,t}}_{\text{destroyed match, not losing UI}} e_t \tag{8}$$

$$u_{t+1}^{UU} = \underbrace{\phi_t(1-p_t^{UI})}_{\text{no meeting, losing UI}} u_t^{UI} + \underbrace{\chi_t^{UI}\Big(\phi_t + (1-\phi_t)\xi\Big)p_t^{UI}}_{\text{turning down a firm, losing UI}} u_t^{UI}$$

$$+ \underbrace{(1-\rho_{f,t}^{UU})}_{\text{not meeting (viable) firm}} u_t^{UU} + \underbrace{\psi\rho_{x,t}}_{\text{destroyed match, losing UI}} e_t \tag{9}$$

$$u_{t+1} = u_{t+1}^{UI} + u_{t+1}^{UU} \tag{10}$$

where $\chi_t^{UI} \equiv \sum_m \mathbb{1}\{S_{m,t+1}^{UI} \le 0\} f(m)$ denotes the probability that a newly formed match between a firm and an insured unemployed worker is not viable. $\rho_{x,t}$ is the employment-to-unemployment transition rate (averaged across employed workers with different match qualities). $\rho_{f,t}^{UU}$ is the rate an uninsured unemployed worker becomes employed and can be different from the rate she meets a vacant firm, p_t^{UU}, since the match quality drawn may not be viable. The definitions of the transition rates between employment and unemployment as well as the job-to-job transition rate can be found in Appendix C.

2.4. Recursive competitive equilibrium

A recursive competitive equilibrium consists of value functions, $W^e(m;\omega)$, $W^{UI}(m;\omega)$, $W^{UU}(m;\omega)$, $U^{UI}(\omega)$, $U^{UU}(\omega)$, $J^e(m;\omega)$, $J^{UI}(m;\omega)$, $J^{UU}(m;\omega)$, and $V(\omega)$; market tightness $\theta(\omega)$; search policy $s^e(m;\omega)$, $s^{UI}(\omega)$ and $s^{UU}(\omega)$; and wage functions $w^e(m;\omega)$, $w^{UI}(m;\omega)$, and $w^{UU}(m;\omega)$, such that, given the initial distribution of workers over the employment status and match productivity, the government's policy $\tau(\omega)$ and $\phi(\omega)$ and the law of motion for z:

1. The value functions and the market tightness satisfy the Bellman equations for workers and firms and the free entry condition, namely, equations (1), (2), (3), (4) and (5)
2. The search decisions satisfy the FOCs for optimal search intensity which are equations (17), (18) and (19)
3. The wage functions satisfy the FOCs for the generalised Nash bargaining rule (equation (6))
4. The government's budget constraint is satisfied each period
5. The distribution of workers evolves according to the transition equations (7), (8), (9) and (10), consistent with the maximising behaviour of agents.

2.5. Solving the model

In order to compute the market tightness (and, in effect, total match surpluses and search effort) in the model, the agents in the economy need to keep track of the distribution of workers over the employment status and match quality $\{e_m\ \forall m, u^{UI}, u^{UU}\}$ as they enter the vacancy creation condition (equation (5)). In order to predict next-period unemployment rate, they need to know the inflow to and outflow from unemployment which are based on this distribution. I use the Krusell and Smith (1998) algorithm to predict the laws of motion for both the insured unemployment rate and the total unemployment rate as a function of current unemployment rate (u) and TFP shock (z). As the distribution of employed workers by match quality does not vary much over time, I use the stochastic steady state distributions as its proxy. I report the performance of this approximation in Appendix D.

[15] Note that employed workers with match quality m exert job search effort in t first before realising if their match quality may be redrawn for $t+1$ production which occurs at rate λ. If redrawing and, at the same time, meeting a new firm, they use the newly drawn m' to decide whether they will do a job-to-job transition.

Table 1
Pre-specified parameters for baseline model (monthly).

Parameter	Description	Value	Source/remarks
β	Discount factor	0.9967	Annual interest rate of 4%
κ	Vacancy posting cost	0.0392	Fujita and Ramey (2012)
μ	Worker's bargaining power	0.5	den Haan et al. (2000)
ϕ_H	UI exhaustion rate	1/6	6 months max UI duration, ETA
$\phi_{L,I}$	UI exhaustion rate	1/12	12 months max UI duration, ETA
$\phi_{L,II}$	UI exhaustion rate	1/18	18 months max UI duration, ETA
b	UI benefit	0.1302	Gruber (1997) given $E(w) = 0.93$
h	Leisure flow	0.7068	Gruber (1997) given $E(w) = 0.93$
$\bar{u}$	UI policy threshold	0.06	ETA
a_u	Search cost function	0.1291	Normalisation
d_u, d_e	Search cost function	1	Christensen et al. (2005), Yashiv (2000)
Additional parameters for the version with the Great Moderation			
$\sigma_{z,pre85}$	SD of TFP shocks	0.0070	BLS and author's own calculation
$\sigma_{z,post85}$	SD of TFP shocks	0.0049	BLS and author's own calculation

Table 2
Calibrated parameters for the baseline model (monthly).

Parameter	Description	Value
l	Matching function	0.5346
δ	Exogenous destruction	0.0239
λ	Redrawing new m	0.5000
ψ	Losing UI after becoming unemp.	0.4900
ξ	Losing UI after meeting firm	0.4605
a_e	Search cost function	0.1430
$\underline{m}$	Lowest match-specific prod.	0.4621
β_1	Match-specific prod. distribution	2.9646
β_2	Match-specific prod. distribution	4.4546
ρ_z	Persistence of TFP	0.9724
σ_z	Standard deviation of TFP shocks	0.0061

3. Calibration

I estimate a subset of the parameters by matching key statistics of the U.S. economy, particularly its labour market. To obtain the counterparts of these statistics from the model, I solve for the policy functions and simulate an economy for T periods where T is large and repeat for 1,000 times. In each simulation, I split the pre- and post-1985 periods at T_1 where $1 < T_1 < T$ and compute relevant statistics including the correlations between output and labour productivity for these two periods.[16]

In the simulation, the only difference between pre- and post-1985 periods is the UI duration policy $\phi(u)$. Specifically, I allow for an increase in its generosity during recessions from pre- to post-1985 periods. As a result, there are two UI duration regimes. When $u < \bar{u}$, the maximum UI duration is six months (standard) in both regimes; however, when $u \geq \bar{u}$, the maximum UI duration is extended to be in total of:

- 12 months from period 1 to T_1 representing January 1948 to March 1985 (the average extended UI duration during the pre-1985 period)
- 18 months from $T_1 + 1$ to T representing April 1985 to June 2014 (the average extended UI duration during the post-1985 period).

Table 1 summarises all the pre-specified parameters while Table 2 describes the calibrated parameters in the model.

Discretisation. I discretise the total factor productivity (z) using Rouwenhorst (1995)'s method to approximate an AR(1) process with a finite-state Markov chain. I use 51 nodes to solve the model and 5,100 nodes by linear interpolation in the simulations. I use 51 equidistant nodes to approximate the Beta distribution of the match-specific productivity $F(m)$ when solving the model and 5,100 nodes by linear interpolation in the simulations. I define $f(m)$ to be $F'(m)/\sum_m F'(m)$ where $F'(m)$ is the probability density function of $F(m)$.

[16] Specifically, T is 5,320 and T_1 is 2,980 so that they are proportional to the data used in this paper. Additionally, I include 200 burn-in periods.

3.1. Pre-specified parameters

The pre-specified parameters are summarised in Table 1. For the discount factor β, I use the value of 0.9967 implying an annual interest rate of 4% which is the U.S. average. I follow Fujita and Ramey (2012) in pinning down the vacancy creation cost κ to be 0.0392 using survey evidence on vacancy durations and hours spent on vacancy posting.[17] I assign μ, the worker's bargaining power, to be 0.5 following den Haan et al. (2000).[18]

ϕ_H and ϕ_L are the UI exhaustion rates during normal periods and recessions respectively. I set ϕ_H to be 1/6 which implies the standard maximum UI duration of 6 months given the monthly frequency. The UI exhaustion rates when UI is extended ($u \geq \bar{u}$) are set to be $\phi_{L,pre85} = 1/12$ for the pre-1985 period and $\phi_{L,post85} = 1/18$ for the post-1985 period implying the maximum UI duration of 12 months (the pre-1985 average) and 18 months (the post-1985 average) respectively. I set $\bar{u}$, the threshold unemployment rate that triggers UI extensions, to be 6% which is on the lower bound of the observed UI extension criteria.

To determine the flow values of unemployed workers, h and, if insured, b, I use the results in Gruber (1997). In particular, he finds the drop in consumption for the newly unemployed workers is 10% when receiving UI and 24% when not receiving UI given the replacement rate of 50%. To obtain the values of h and b given a set of parameters, I first guess the mean wage for the newly unemployed, set the values of h and b to be 76% and 14% of the guess respectively, and solve the model to obtain the policy functions. I then simulate the model to check if the guess is close to the simulated counterpart. If it is not, I replace the guessed wage for the newly unemployed with the one from the simulation, obtain new values of h and b and repeat the same process until the two are close enough.

The slope of the search cost function for the unemployed a_u is normalised such that the search effort of the uninsured unemployed s^{UU} is unity when the economy is in the steady state, similar to Nagypál (2005). The power parameters in the search cost functions for both employed and unemployed workers (d_e and d_u) are set to unity in line with Christensen et al. (2005) and Yashiv (2000). That is, the search cost function is quadratic.[19]

3.2. Calibrated parameters

I use the simulated method of moments to assign values to the remaining eleven parameters $\{l, \delta, \lambda, \psi, \xi, a_e, \underline{m}, \beta_1, \beta_2, \rho_z, \sigma_z\}$ by matching twelve moments.[20] ψ is calibrated because of the lack of precise data on the share of newly unemployed workers who are UI eligible. Notably, justified causes in case of quits vary across states. Since quits generally represent a large fraction of total separations,[21] these varied rules are important for a reliable calculation of the number of UI eligible workers; however, not all causes of quits can be distinguished in the separation data. Similarly, ξ is calibrated due to the lack of data on UI monitoring.[22] The values of the calibrated parameters are reported in Table 2. The targeted moments used in the calibration are[23]:

- The first and second moments of the unemployment rate, the job destruction rate and the job finding rate,[24]
- The first moment of the job-to-job transition rate, the average unemployment duration and the insured unemployment rate,
- The second moment and the autocorrelation coefficient of the labour productivity, and
- The correlation between output and labour productivity during the pre-1985 period.

I describe the data source in this calibration exercise in Appendix A. The model's generated moments are reported in Table 3 along with their empirical counterparts. Table 8 shows other related moments not targeted in the calibration. Both tables also report the results under the case with an alternative worker's bargaining power ($\mu = 0.7$) as a robustness check.

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[17] Fujita and Ramey (2012) find the vacancy cost to be 17% of a 40-hour work week. Normalising the mean productivity to unity, this gives the value of 0.17 per week or 0.0392 per month. The actual mean productivity may be higher than (but not greatly different from) unity due to truncation from below of the match-specific quality.

[18] As a robustness check, I also report the main results with the worker's bargaining power being 0.7 as used in Shimer (2005).

[19] Despite d_e and d_u not being calibrated, the model still generates a realistic elasticity of unemployment duration to UI extensions. This result is discussed further in Section 4.1.

[20] The calibrated parameters are to minimise the sum of squared residuals of percentage changes between the model-generated moments and their empirical counterparts.

[21] BLS's quits-to-layoffs-and-discharges ratio is on average 1.4 between 2000-2017.

[22] In general, after refusing a job offer, one can still collect UI benefits if and only if the said job is not deemed "suitable" whose definition also differs across states.

[23] It is inevitable that each parameter affects more than one moment; however, $\{l, \delta, a_e\}$ are primarily calibrated to match respectively the average job finding rate, job separation rate and job-to-job transition rate. $\{\rho_z, \sigma_z\}$ are to match statistics related to the labour productivity. λ is to match the second moment of the job separation rate. Parameters for the match quality distribution $\{\underline{m}, \beta_1, \beta_2\}$ are to match the first and second moments of the unemployment rate as well as the second moment of the job finding rate. Parameters related to the UI policy $\{\xi, \psi\}$ are calibrated to match the insured unemployment rate and the average unemployment duration.

[24] Fujita and Ramey (2012) calibrate a parameter similar to λ in this paper to match the persistence of the job separation rate. Their λ implies that a match is redrawn on average every 2-3 months (every 2 months in this paper). However, their assumptions are slightly different as every new match starts at the top of the match quality distribution that is log-normal.

Table 3
Targeted moments.

Moment	Data	Baseline model	$\mu = 0.7$	Single m	Great moderation
E(u)	0.0583	0.0564 (0.0048)	0.0634 (0.0051)	0.0572 (0.0009)	0.0567 (0.0053)
E(ρ_f)	0.4194	0.4387 (0.0194)	0.4335 (0.0166)	0.4113 (0.0072)	0.4611 (0.0209)
E(ρ_x)	0.0248	0.0256 (0.0007)	0.0274 (0.0009)	0.0248 (0.0000)	0.0256 (0.0007)
E(ρ_{ee})	0.0320	0.0317 (0.0004)	0.0316 (0.0003)	– –	0.0317 (0.0003)
E(u_{dur}) (weeks)	15.4287	12.3667 (1.3213)	12.0494 (0.8769)	*Not targeted* *Not targeted*	11.8921 (1.4983)
E(u^{UI})	0.0290	0.0331 (0.0038)	0.0358 (0.0038)	0.0274 (0.0007)	0.0332 (0.0042)
std(u)	0.1454	0.1637 (0.0229)	0.1765 (0.0158)	0.0741 (0.0027)	0.1717 (0.0259)
std(ρ_f)	0.0999	0.1207 (0.0144)	0.1149 (0.009)	0.049 (0.0029)	0.1290 (0.0159)
std(ρ_x)	0.0890	0.0836 (0.0158)	0.0952 (0.0115)	– –	0.0772 (0.018)
std(LP)	0.0131	0.0124 (0.0006)	0.0120 (0.0005)	0.0126 (0.0006)	0.0122 (0.0006)
corr(LP, LP_{-1})	0.7612	0.7660 (0.0196)	0.7626 (0.0192)	0.7717 (0.0186)	0.7656 (0.0201)
corr($y, LP)_{pre85}$	0.7015	0.7620 (0.0958)	0.7567 (0.0954)	*Not targeted* *Not targeted*	0.7272 (0.1273)

Note: Standard errors are in parentheses. ρ_f denotes the job finding rate. ρ_x denotes the job separation rate. ρ_{ee} denotes the job-to-job transition rate. u_{dur} denotes the average unemployment duration. LP denotes labour productivity.

4. Results

4.1. Performance

As shown in Table 3, the baseline model, despite being over-identified, matches the twelve targeted moments quite well overall including the first moments of the unemployment rate, the job finding rate, the job destruction rate and the job-to-job transition rate. It also matches the characteristics of the labour productivity quite well. The average job finding rate is somewhat higher than the data whilst unemployment and job findings exhibit slightly higher fluctuations than the data. The mean unemployment duration is lower than the data but this is partly due to the Great Recession period where there was an unprecedented spike in average duration of unemployment. Despite the curvature of the search cost function (d_e and d_u) not being calibrated, the model does produce an elasticity of unemployment duration to changes in the maximum potential UI duration (an important statistic that responds to job search effort) of 0.09 that is in line with the existing literature.[25] I provide a more-detailed analysis of non-targeted business cycle moments in the later subsection.

Additionally, I also find the path of TFP shocks that yields a detrended output series identical to the data (using the parameters in Table 1 and 2). With this path of TFP shocks, I compare the model-generated series of relevant macroeconomic variables to the data. Fig. 4 shows that the model produces similar dynamics of de-trended unemployment, job findings and unemployment durations while job destructions fluctuate too little comparing to the data. It is expected that the model-generated series may be different from the raw data as shown in Fig. 5 since low frequency changes are not accounted for. That being said, the empirical average unemployment duration is much higher than the model counterpart. However, the model's insured unemployment series is close to the data from both the cyclical and raw-data aspects, as shown in Fig. 6, especially during recessions when the insured unemployment rate spikes.

[25] For example, Moffitt and Nicholson (1982) find that a 1-week increase in the potential UI duration increases unemployment duration by 0.1 weeks. Moffitt (1985) and Katz and Meyer (1990) respectively find this to be around 0.15 weeks and between 0.16-0.2 weeks. Hence, the model generates an elasticity that is on the lower bound. Increasing d_u would increase the elasticity as it implies that search intensity is more sensitive to returns from search.

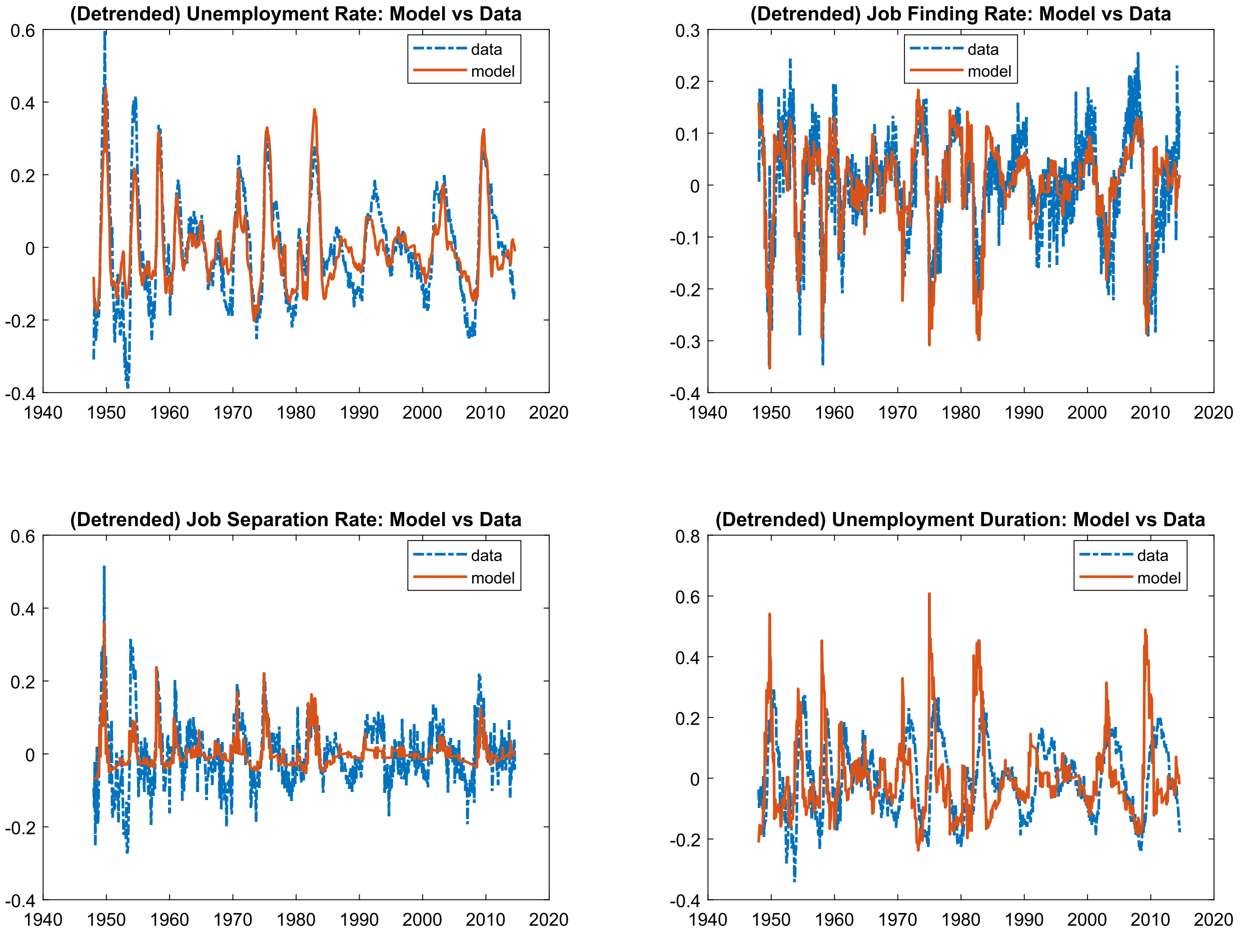

Fig. 4. Model-generated (solid) and empirical (dashed) detrended series of main variables. (For interpretation of the colours in the figure(s), the reader is referred to the web version of this article.)

4.2. *Correlation between output and labour productivity*

With respect to the labour productivity puzzle, the model can explain a significant part of the drop in the procyclicality of the labour productivity. Particularly, it can generate over 40 percent of the observed fall in the correlation between output and labour productivity from pre- to post-1985 periods (a drop from 0.76 to 0.59 as compared to a drop from 0.70 to 0.30) as shown in Table 4. Note that a standard search and matching model without any change in the UI extension generosity (i.e. no change in ϕ_L) will not be able to produce any shift in this correlation since the policy functions will remain the same in both pre-1985 and post-1985 periods. Despite not targeted, the overall correlation produced by the model is in fact quite close to the data (0.65 as compared to 0.62). The model-generated pre-1985 correlation, which is targeted in the calibration, is slightly higher than that in the data (0.76 as compared to 0.70), and the correlation difference is larger for the post-1985 period (0.59 as compared to 0.30).[26]

Next to the baseline model in Table 4, I consider a different parameter for the worker's bargaining power (μ) and find that the results remain largely the same. I also consider a scenario where there is no heterogeneity in match quality which is similar to Mitman and Rabinovich (2014) except for the UI duration policy that is unemployment-dependent.[27]

[26] Since the generosity of UI extensions varies a lot from one recession to another as seen in Fig. 3, one could think that the huge UI extensions in the Great Recession could be the main driver of the results. To address this issue, I have also calibrated the model to feature more than two levels of UI duration generosity. Specifically, I let the maximum UI duration be equal to the observed generosity in each recession and end up with five levels of generosity. I find that the main results are robust to this. The drop in the correlation between output and labour productivity is even slightly more pronounced with finer levels of UI generosity.

[27] In this scenario, I use one single match productivity equal to the median match productivity in the baseline case. In this calibration without heterogeneous match quality, there are seven parameters to match seven moments. Four parameters $\{\lambda, \underline{m}, \beta_1, \beta_2\}$ are dropped and the following five moments are no longer being targeted: the first moments of the average unemployment duration and job-to-job transitions, the second moments of unemployment and job separations, and the correlation between output and labour productivity pre-1985.

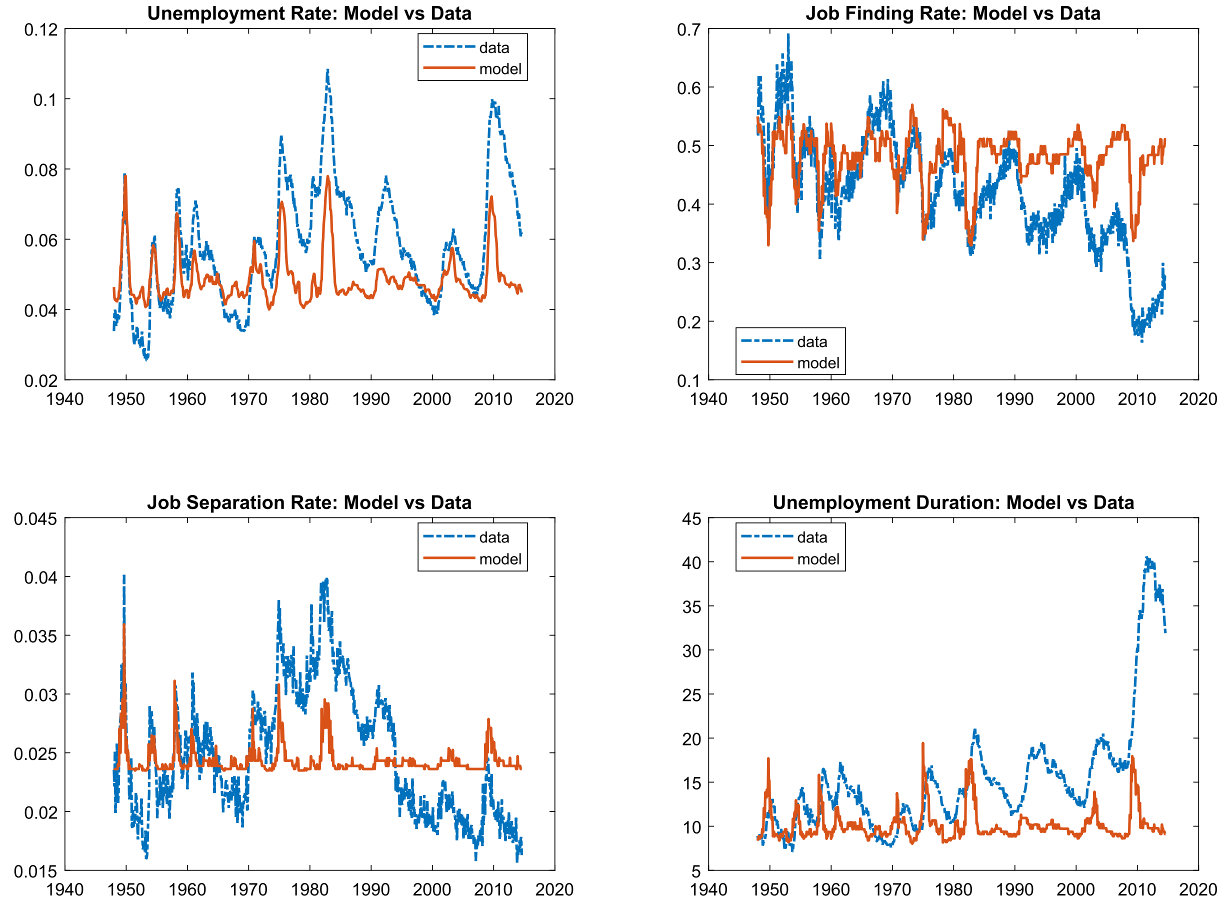

Fig. 5. Model-generated (solid) and empirical (dashed) raw series of main variables.

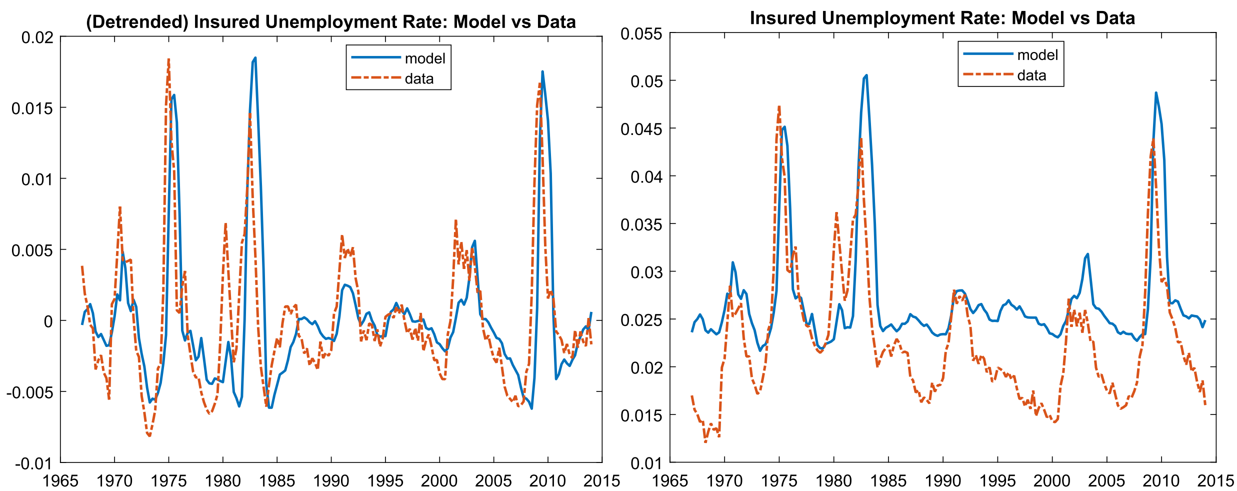

Fig. 6. Model-generated (solid) and empirical (dashed) series of the insured unemployment rate: detrended (left) and raw series (right).

Once recalibrated, Table 4 (column "Single m") shows that the heterogeneous match quality feature is vital to generate (1) a less-than-perfect correlation between output and labour productivity, and (2) any change in the correlation itself following a more generous UI duration policy. In addition, I present results when the model is calibrated to the U.S. economy before the start of the Great Recession (column "Pre-2008" in Table 4). The effect of an increase in UI extension

Table 4
Correlation between output (y) and labour productivity (LP).

	Data	Baseline	$\mu = 0.7$	Single m	Pre-2008	Great moderation	Fixed τ
$\text{corr}(y, LP)$	0.6186	0.6553	0.6569	0.9940	0.6675	0.6718	0.6889
		(0.0991)	(0.0980)	(0.0006)	(0.0916)	(0.1027)	(0.0804)
$\text{corr}(y, LP)_{pre85}$	0.7015	0.7620	0.7567	0.9952	0.7829	0.7272	0.7941
		(0.0958)	(0.0954)	(0.0007)	(0.0878)	(0.1273)	(0.0881)
$\text{corr}(y, LP)_{post85}$	0.2954	0.5911	0.6106	0.9926	0.6258	0.6128	0.6499
		(0.1201)	(0.1173)	(0.0001)	(0.1112)	(0.118)	(0.0959)
$\Delta\,\text{corr}(y, LP)$	0.4061	0.1709	0.1461	0.0026	0.1571	0.1144	0.1442

Note: $\Delta\,\text{corr}(y, LP)$ denotes the change in the correlation between output and labour productivity from the pre-1985 to the post-1985 periods. Standard errors are in parentheses.

generosity on $\Delta\,\text{corr}(y, LP)$ slightly weakens due to a lower mean unemployment rate and a higher mean job finding rate.[28]

The success of the model in generating a sizable drop in the correlation is due to the fall in the UI exhaustion rate during high unemployment (the fall in ϕ_L) from the pre-1985 to post-1985 periods which alters the policy functions in the model: (i) match surplus and (ii) job search effort as a function of unemployment. A smaller ϕ_L in the post-1985 period lowers match surpluses, making worker-firm matches with low match qualities unviable, and lifts up the average labour productivity during the recessions. At the same time, a smaller ϕ_L lowers the job search effort and, in effect, employment, thereby prolonging the UI extensions once triggered.

Match surplus. The discontinuity in the UI duration function $\phi(u)$ creates a discontinuity in the match surplus as a function of unemployment as shown in Fig. 7.[29] Whenever unemployment is above the threshold ($u \geq \bar{u}$), the function $\phi(u)$ falls from ϕ_H to ϕ_L. The fall in $\phi(u)$ increases the outside option of workers and decreases the surpluses from working for most workers.[30] Therefore, it is less likely for matches to be/remain formed, especially those with low match quality m. This puts an upward pressure on the average labour productivity against negative shocks to z and results in a less-than-perfect correlation between output and labour productivity. Since $\phi_{L,post85} < \phi_{L,pre85}$, the post-1985 match surpluses fall even further whenever $u \geq \bar{u}$ comparing to those in the pre-1985 period, and only the matches with higher match qualities exist in post-1985 recessions. This means, in the post-1985 period, the positive response of labour productivity upon a negative shock is stronger and results in a lower correlation between output and labour productivity compared to the pre-1985 period.

Job search effort. Similar to the previous argument, the discontinuity in $\phi(u)$ creates a drop in the job search effort and the job finding rate for the insured unemployed around $\bar{u}$ where $\phi(u)$ falls from ϕ_H to ϕ_L as seen in Fig. 8. When $u \geq \bar{u}$, there are fewer meetings and, as a result, higher unemployment which feeds back to the UI policy $\phi(u)$ to remain low at ϕ_L for longer.[31] With $\phi_{L,post85} < \phi_{L,pre85}$, the post-1985 job search effort fall even further whenever $u \geq \bar{u}$ compared to those in pre-1985 periods. Unemployment is thus more likely to remain high and lengthen the effects the UI extensions have on the falling correlation between output and labour productivity in the post-1985 period.[32]

It is useful to note that the uninsured unemployed, who have the lowest outside option, have higher search effort and job finding rate than do the insured unemployed. Based on CPS Basic Monthly Data and CPS Displaced Worker, Employee Tenure, and Occupational Mobility Supplement, Table 1 of Rujiwattanapong (2019) shows that unemployed workers who never received UI benefits during an unemployment spell find a job at a faster rate than current UI recipients.

4.3. Impulse response functions

The impulse response functions (IRFs) of key variables in the model are useful in demonstrating how the UI duration policy affects the correlation between output and labour productivity. Fig. 9 and 10 show respectively the IRFs of output

[28] In the "Pre-2008" calibration, empirical moments are computed using observations up to December 2007. As the parameters are calibrated to generate a slightly lower average unemployment rate and a higher job finding rate, UI extensions are less likely to be triggered.

[29] The surplus in Fig. 7 is plotted for the middle nodes on the grids of match quality m and aggregate productivity z. The match surplus indeed increases in these two arguments but not in a discontinuous fashion like in the dimension of unemployment u.

[30] Specifically, the surpluses of workers with history $\{e, UI\}$ fall as shown in Fig. 7. We can see that the surplus for workers with history UU, however, increases slightly with lower $\phi(u)$ because it is better for this type of workers to become re-employed and increase the likelihood of receiving UI in the event that they return to unemployment.

[31] In this model, the persistence of UI extensions interacts with the persistence of unemployment which is in line with the hypothesis in Mitman and Rabinovich (2014) where a longer UI duration increases the persistence of unemployment.

[32] It is useful to note that if workers are risk-averse, instead of risk-neutral, the negative response of job search effort to UI extensions is expected to be weaker since they would prefer a steadier stream of consumption and becoming uninsured unemployed (without UI benefits) would lower their expected utility. However, the risk neutrality assumption implies transferable utility which makes the model easier to solve. Hence, the results in this paper can be seen as the upper bound of the effects of UI extensions.

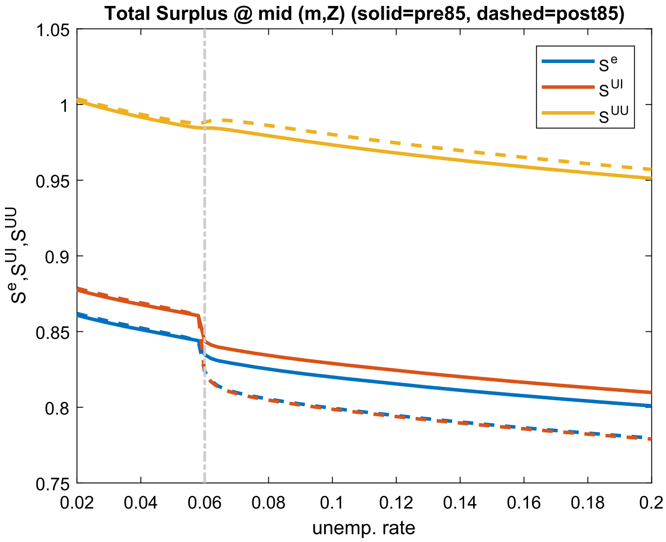

Fig. 7. Total match surpluses by previous employment statuses, $S^i; i \in \{e, UI, UU\}$, plotted against the unemployment rate (u): for the match-specific and total factor productivities at the middle nodes.

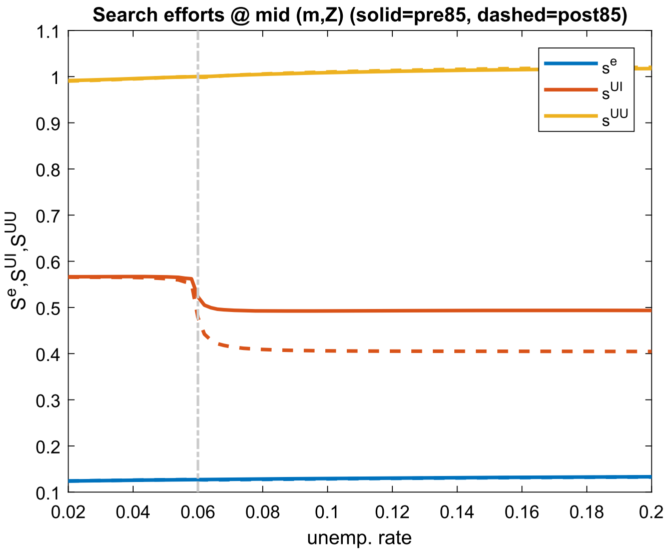

Fig. 8. Conditional job finding rates (worker's meeting rates) by employment statuses plotted against the unemployment rate: for the match-specific and total factor productivities at the middle nodes.

(y), labour productivity (LP) and average match quality ($E(m)$) to 1% and 2% negative TFP (z) shocks from its steady state for pre-1985 (solid lines) and post-1985 (dashed lines) periods.

In the case of a 1% negative deviation, there is little difference between the responses of variables in pre- and post-1985 periods because unemployment does not exceed $\bar{u}$ and trigger UI extensions. Labour productivity recovers as soon as the shock subsides while output reaches its trough 6 months after the shock hits for both pre- and post-1985 periods. Therefore, the correlation between output and labour productivity is less than perfect under a 1% negative TFP shock but there is hardly any difference between pre- and post-1985 periods.

On the contrary, the IRFs between pre- and post-1985 periods are very different when the size of the shock is instead 2% negative deviation from the steady state. This is solely because the UI extension is triggered for the post-1985 period (from the fifth month onwards) but not in the pre-1985 period where the IRFs are almost identical to the 1% deviation case.[33] Despite its negative response throughout, labour productivity recovers at a faster rate in the post-1985 period than in the

[33] If there was no change in the maximum UI duration, Fig. 9 and 10 would have looked identical with only a change in the scale.

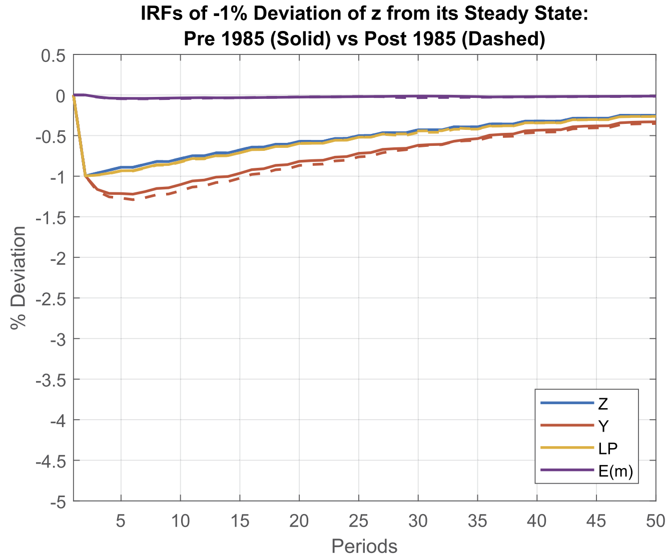

Fig. 9. IRF of 1% negative TFP shock (UI extensions not triggered).

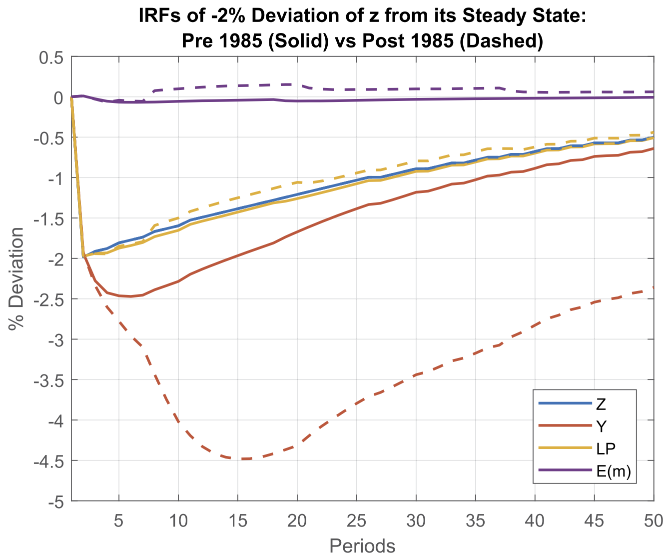

Fig. 10. IRF of 2% negative TFP shock (UI extensions triggered). Note: $\{Z, Y, LP, E(m)\}$ denote respectively total factor productivity, output, labour productivity (output per worker) and the average match quality.

pre-1985 period once UI extension is in place. More starkly is the response of output that reaches its trough 15 months after the initial shock, almost one year later than the cases without UI extension (the pre-1985 period with 2% shock and both pre- and post-1985 periods with 1% shock). The quicker recovery of the labour productivity combined with the highly persistent negative output response makes the correlation between output and labour productivity in the post-1985 period much smaller than that in the pre-1985 period.

In terms of the match quality, an extension of UI tends to raise the overall match quality as shown in Fig. 10 (particularly for the post-1985 period) making it countercyclical. Hagedorn and Manovskii (2013) use the sum of labour market tightness during a job spell as a proxy for individual match quality and show empirically that it is in fact procyclical. This finding is still consistent with this paper since individual match qualities are indeed higher in good times due to a higher match durability. However, the endogenous job separation margin in this paper implies that lower quality matches can also survive in booms which bring down the average match quality.

Table 5
Decomposition of UI effects on $\Delta\,\mathrm{corr}(y, LP)$.

	Data	Baseline model	S-fixed	s-fixed	θ-fixed
$\Delta\,\mathrm{corr}(y, LP)$	0.4061	0.1709	0.0846	0.1000	0.1370
Change from baseline	n/a	–	−0.0863	−0.0709	−0.0339

Note: "S-fixed" denotes the case where the match surplus is fixed to the pre-1985 period throughout the simulation. Analogously, "s-fixed" and "θ-fixed" are the cases where job search effort and market tightness are fixed to the pre-1985 period respectively.

4.4. Decomposition of countercyclical UI duration effects

I decompose the effect of the increasing generosity of UI extensions on the procyclicality of labour productivity and study the contribution of the following three channels: (1) match surplus, (2) job search effort and (3) vacancy creation. The results are reported in Table 5. I measure the contribution of a given channel by studying the drop in the output-productivity correlation, $\Delta\,\mathrm{corr}(Y, LP)$, when that channel is assumed to not respond to the increase in the UI extension generosity from pre-1985 periods (12 months maximum UI duration) to post-1985 periods (18 months maximum UI duration).[34] If a given channel is unimportant for $\Delta\,\mathrm{corr}(Y, LP)$, "fixing" that particular channel to the pre-1985 UI generosity would not significantly alter the value of $\Delta\,\mathrm{corr}(Y, LP)$ from that in the baseline model (which is 0.17). On the contrary, if a given channel is important and it is fixed, $\Delta\,\mathrm{corr}(Y, LP)$ would expectedly be smaller than 0.17. The smaller is $\Delta\,\mathrm{corr}(Y, LP)$ in each scenario, the less able is the model to generate a drop in the procyclicality of labour productivity without allowing a given channel to respond to the UI generosity increase.

First, I measure the extent to which the match surplus response (to more generous UI duration) affects the falling procyclicality of the labour productivity. I do this by assuming that both workers and firms use the pre-1985 match surpluses throughout the simulation to make decisions on match formation and dissolution, i.e. the policy functions for match surpluses are fixed at the pre-1985 periods ("S-fixed" in Table 5). Next, I similarly fix the job search policy at the pre-1985 periods and study the change in the correlation between output and output per worker ("s-fixed" in Table 5). Finally, I study the contribution of the vacancy creation channel by fixing the market tightness at the pre-1985 periods, i.e. the worker's meeting rate per search unit and the firm's meeting rate are fixed at the pre-1985 periods ("θ-fixed" in Table 5).[35]

It turns out that the responses of match surpluses and job search efforts to more generous UI extensions explain a substantial part of the drop in the output-labour-productivity correlation (respectively 50% and 41% of the model's generated drop – equivalent to 21% and 17% of the empirical drop) as shown in Table 5. Vacancy creation does affect the drop in the procyclicality of labour productivity, albeit to a lesser extent (20% of the model's generated drop). It is useful to note that in all three cases, the overall correlation, $\mathrm{corr}(y, LP)$, is around 0.71-0.73 and higher than the baseline (0.65).

4.4.1. The role of search efforts

It is rather surprising that the search effort channel contributes almost as much as the match surplus channel considering that the former only affects the insured unemployed whilst the latter affects most workers. As job search is procyclical in this paper, it is useful to investigate further the role of its cyclical behaviour given varied empirical findings in the literature.[36] Particularly, I continue with the "s-fixed" case (where search responds up to 12-month maximum UI duration) and impose further restrictions on job search such that it does not respond to (1) aggregate productivity z, (2) unemployment u (effectively UI extensions) and (3) UI status (the insured and uninsured unemployed exert the same search efforts). I then study the resulting drop in the output-productivity correlation in each case. For the first two cases, job search is fixed to respond to only the average values of z and u respectively.

Column "s indep. of z" in Table 6 suggests that the assumption that search is procyclical (positively co-moving with z) contributes rather little to $\Delta\,\mathrm{corr}(y, LP)$ as it hardly changes once job search is assumed to not respond to z. However, the response of job search to UI extensions (the change in the maximum UI duration from 6 to 12 months) does matter for the drop in the correlation between output and labour productivity as $\Delta\,\mathrm{corr}(y, LP)$ falls by 0.03 without this response (see column "s indep. of u" in Table 6). Nonetheless, the response of job search in the "s-fixed" case where the maximum UI duration is cut from 18 to 12 months has a more drastic impact on the correlation drop as $\Delta\,\mathrm{corr}(y, LP)$ falls by 0.07 (see Table 5). This suggests that the response of job search to the maximum UI duration and its impact on $\mathrm{corr}(y, LP)$

[34] This is equivalent to imposing that a given channel behaves as if the UI exhaustion rate stays at $\phi_{L,I}$ even in post-1985 periods, implying that the maximum UI duration is always 12 months when there are UI extensions. In the baseline model, UI extensions imply 12 months of maximum UI duration in pre-1985 periods and 18 months of maximum UI duration in post-1985 periods.

[35] It is worth noting that fixing the market tightness at the pre-1985 periods would affect the value of a joint match surplus between a worker and a firm in the post-1985 periods. I assume that workers and firms use the actual post-1985 match surpluses (unaffected by the fixing of the market tightness) to decide whether to form or dissolve a match. Therefore, this exercise shows the effect of vacancy creation only on the worker-firm meeting rates.

[36] Gomme and Lkhagvasuren (2015) find that job search is procyclical for the short-term unemployed and on average acyclical. DeLoach and Kurt (2013) also find that it is acyclical. However, Shimer (2004) and Mukoyama et al. (2018) find that job search is countercyclical. Çenesiz and Guimarães (2019) provide a great literature review on the cyclicality of search efforts.

Table 6
Decomposition of UI effects on $\Delta\,\text{corr}(y, LP)$ via the job search channel.

	s-Fixed	s indep. of z	s indep. of u	s indep. of UI status
$\Delta\,\text{corr}(y, LP)$	0.1000	0.0923	0.0722	0.0672
Change from s-fixed	–	−0.0077	−0.0278	−0.0328

Note: "s-fixed" denotes the case where the job search policy is fixed to the pre-1985 period throughout the simulation. "s indep. of i" extends from "s-fixed" and denotes the case where the job search policy, in addition to being fixed to the pre-1985 periods, does not respond $i \in \{z, u, \text{UI status}\}$ where z is the aggregate productivity and u is the unemployment rate.

are not linear and that they become stronger at a longer UI duration.[37] If we assume that job search does not respond to UI extensions at all, UI extensions can still affect labour productivity via search efforts but only at the extensive margin because the insured unemployed still search less hard than the uninsured unemployed. When UI is extended, the share of insured unemployed workers increases which implies that the average job search intensity (and, therefore, job finding rate) amongst the unemployed drops causing more persistent unemployment and triggering UI extensions. Column "s indep. of UI status" in Table 6 shows that if this extensive margin is shut down and the insured unemployed search as hard as the uninsured unemployed, $\Delta\,\text{corr}(y, LP)$ falls even further than when we impose zero microeconomic effect of UI extensions (column "s indep. of u").

The importance of the search effort channel on productivity is not at odds with empirical evidence in Hagedorn et al. (2013), among others, that the microeconomic effect (via search intensity) of UI extensions on unemployment is rather small. The role of job search in this paper is primarily to make unemployment more persistent and maintain it above $\bar{u}$ such that the prolonged UI extensions put upward pressure on labour productivity during recessions.[38]

4.5. On the great moderation

Since the mid 1980s, apart from a significant drop in the procyclicality of the labour productivity, the U.S. economy (among others) also experienced a substantial reduction in the output volatility. This phenomenon is coined "the Great Moderation".[39] The Great Moderation can potentially change the effect of the countercyclical UI duration policy on the labour productivity since the decreased volatility of the business cycle fluctuations implies that large negative shocks are less likely to occur after the mid 1980s and, therefore, high unemployment that triggers UI extensions is less likely to occur.

To quantify how much the Great Moderation can impact the UI effect on the labour productivity, I introduce a drop in the variance of the aggregate productivity z from the pre-1985 period to the post-1985 period ($\sigma_{z,pre85} > \sigma_{z,post85}$). I set the difference between the two variances based on the empirical values of the labour productivity series. Specifically, I compute the ratio of the pre-1985 standard deviation to the overall standard deviation of the detrended labour productivity series and multiply it with the calibrated value of the standard deviation of the aggregate productivity shock σ_z to get $\sigma_{z,pre85}$. I do the same for the post-1985 period to obtain $\sigma_{z,post85}$. I report the values in Table 1. Based on these values, I solve the model again where not only the UI duration policy changes from the pre-1985 to post-1985 periods but the standard deviation of the TFP shocks also drops from the pre-1985 to post-1985 periods. With the resulting policy functions (total match surplus and job search effort), I redo the simulation where the Great Moderation is featured and report correlation statistics in Table 4.

Table 4 shows that the Great Moderation does have a negative impact on the effect the countercyclical UI policy has on the labour productivity. In particular, the drop in the correlation between output and labour productivity from pre- to post-1985 periods is smaller when the volatility of TFP shocks is reduced after the mid 1980s (a drop of 0.11 as compared to 0.17 in the baseline case). That being said, the fall in the procyclicality of the labour productivity is still sizable and amounts to 28 percent of the empirical drop in this correlation.

4.6. UI financing

The baseline model assumes that UI benefit payments are financed by levying lump sum tax on producing firms and the UI budget constraint is satisfied every period. This is set so that the model is of general equilibrium and in accordance with the fact that UI payments in the U.S. are financed partly by levying an experience rated payroll tax (alongside the federal and state components). However, as there is a cap to the experience rated component, one could argue that the UI budget constraint may not be satisfied every period. In this exercise, I study what happens when the lump sum tax is constant and set to satisfy the UI budget constraint on average.

[37] This non-linear response of job search can also be seen in Fig. 8 where s^{UI} drops by a larger magnitude when the maximum UI duration increases from 12 to 18 months than when it increases from 6 to 12 months.

[38] Further, the elasticity of unemployment duration to additional week to UI duration is in line with (and on the lower bound of) the existing empirical estimates as discussed in Section 4.1.

[39] McConnell and Perez-Quiros (2000) is amongst the first to document this phenomenon.

I find that fixing the lump sum tax slightly lessens the effect of UI extensions on the cyclicality of labour productivity. As shown in Table 4, the drop in the correlation between output and labour productivity from pre- to post-1985 periods is 0.14 (comparing to 0.17 in the baseline model). The correlation drop is smaller because once the lump sum tax becomes acyclical (instead of countercyclical), total match surpluses are less negatively affected by UI extensions during recessions than those of the baseline model. As a result, there are fewer endogenous match separations, more matches being formed and a smaller drop in the number of vacancies. All these channels lead to the viability of lower match qualities that could not prevail in the baseline model; therefore, there is less upward pressure on labour productivity during recessions, and the correlation between output and labour productivity does not fall as much as in the baseline model. Risk neutrality, however, implies that setting a fixed lump sum tax does not alter the main results substantially.

4.7. On-the-job search

On-the-job search (OJS) allows employed workers to improve their match qualities by being matched with a new firm. At the same time, unemployed workers are more likely to accept a job offer with a low match quality as it is possible to improve their match qualities later in the future via OJS. This has implications on the cyclical behaviour of labour productivity. Without OJS, upon a negative shock to the economy (large enough to trigger UI extensions), there will be less separations of low quality matches (since there are fewer to begin with) than in the case with OJS. This means that the upward pressure on labour productivity when there are UI extensions will be weaker in the absence of OJS. I find that, once OJS is removed, the drop in the correlation between output and labour productivity (of 0.15 which equals 38% of the empirical drop) is somewhat smaller than in the baseline model with OJS (of 0.17 which equals 42% of the empirical drop). It is useful to note that the model without OJS, once recalibrated, still generates realistic moments in the aggregate labour market with the primary exception of the correlation between unemployment and vacancies where it fails to capture the negative relationship observed in the data. $\text{corr}(u, v)$ from the baseline model (with OJS) is -0.36 whilst it is 0.68 from the model without OJS.[40]

4.8. Wage properties and UI status

As workers use the value of remaining unemployed or returning to unemployment as their outside option during the wage bargaining process, wages as well as their business cycle properties therefore depend on employment statuses. Fig. 11 depicts how wages interact with the unemployment rate and the workers' previous employment statuses. Given the same match quality and that unemployment is low ($u < \bar{u}$), workers who were employed last period receive a higher wage than those who were insured unemployed last period. The uninsured unemployed receive the lowest wage reflecting that they have the lowest outside option (the value of remaining unemployed).[41] When $u \geq \bar{u}$ (UI is extended), the outside options for the previously employed and insured unemployed increase whilst that of the previously insured unemployed decrease. A more generous UI extension emphasises these responses, particularly for the previously insured unemployed whose wage could be as high as that of the previously employed given the same match quality. Elasticities of wages with respect to productivity and unemployment are shown in Table 7. The model generates a relatively high elasticity of wages with respect to productivity (0.83) when comparing to the data (0.64 as reported by Hagedorn and Manovskii (2011) using CPS employment data).[42] As wages fluctuate more than in the data, this leaves less room for firms' profits to respond to economic conditions which may partly explain why vacancies in the model are less volatile than in the data (as reported in Table 8). By employment statuses, the outside option of workers who are uninsured unemployed is constant (h) implying that the joint match surplus and the profits of firms matched with this type of workers do not fluctuate as much (also depicted in Fig. 7) as with workers of other types. Therefore, the wage elasticities with respect to either productivity or unemployment of workers who were previously uninsured unemployed, $\varepsilon(w^{UU}, z)$ and $\varepsilon(w^{UU}, u)$, are the highest.

4.9. Other business cycle properties

With regards to related moments that are not targeted (shown in Table 8), the model does a good job in matching the dynamics of the employment rate and the insured unemployment rate as well as the cyclicality of unemployment, job findings and job destructions. The correlation between unemployment and vacancies is however moderately negative

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[40] The finding that an introduction of OJS into an otherwise standard search and matching model with endogenous job separation helps generate a realistic Beveridge curve is also presented in Fujita and Ramey (2012). The strong countercyclicality of unemployment in a model with endogenous separation means that the large positive responses of unemployment in recessions increase the probability that a vacancy is filled (which then induces more vacancies to be posted). This counteracts the negative impact of recessions on vacancies and leads to a positive comovement between unemployment and vacancies. OJS helps mitigate this effect by expanding the pool of job searchers to include employed workers whose search does not vary as much with the business cycle and lessening the upward pressure on the job-filling probability in recessions.

[41] Wage can increase with tenure in 3 ways: (1) from the first to second period of employment due to the change in the outside options for those previously unemployed conditional on m, (2) on-the-job search and (3) positive outcomes of match quality redraws.

[42] Hagedorn and Manovskii (2011) obtain a smaller elasticity of 0.45 when using employment data from the Current Employment Statistics (CES). Despite a relatively high elasticity of wages in this paper, a standard MP model under Shimer (2005)'s calibration strategy delivers a higher number of 0.964.

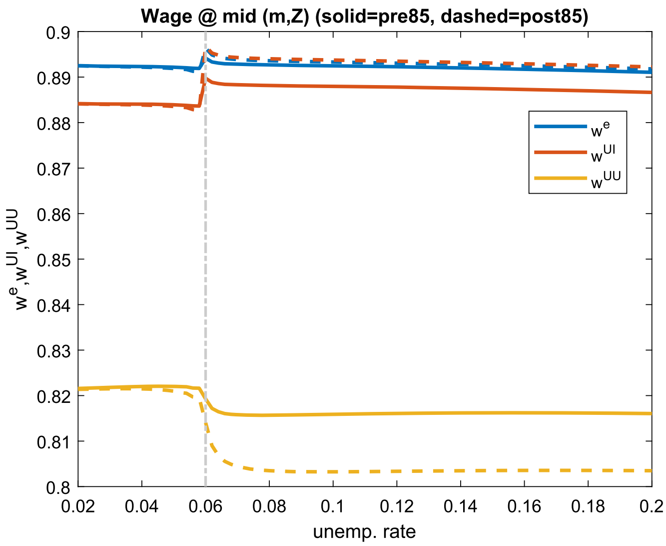

Fig. 11. Wages by previous employment statuses, $w^i; i \in \{e, UI, UU\}$, plotted against the unemployment rate (u): for the match-specific and total factor productivities at the middle nodes.

Table 7
Elasticities of wages with respect to productivity and unemployment.

Moment	Baseline model	Moment	Baseline model
$\varepsilon(w, z)$	0.8345	$\varepsilon(w, u)$	−0.5343
$\varepsilon(w^e, z)$	0.8238	$\varepsilon(w^e, u)$	−0.5173
$\varepsilon(w^{UI}, z)$	0.7747	$\varepsilon(w^{UI}, u)$	−0.3744
$\varepsilon(w^{UU}, z)$	1.2780	$\varepsilon(w^{UU}, u)$	−1.0370

Note: $\varepsilon(x, y)$ denotes the elasticity of x with respect to y and is defined as $\varepsilon(x, y) \equiv corr(x, y)\sigma_x/\sigma_y$ where σ_x is the standard deviation of x. $\{w^e, w^{UI}, w^{UU}\}$ are respectively average wages of employed workers who were, in the previous month, employed, insured unemployed and uninsured unemployed.

(-0.37) whilst it is strongly negative in the data (-0.88).[43] Apart from the fall in the procyclicality of labour productivity, the correlations between output and a few labour market variables have also become somewhat smaller (including the job finding rate, the job separation rate and vacancies) from the pre-1985 to the post-1985 periods. Without targeting them, the model can produce these weakened correlations as also shown in Table 8.

Hagedorn and Manovskii (2011) study the correlations between labour productivity and labour market variables such as unemployment, vacancies and labour market tightness. Whilst a standard Mortensen-Pissarides (MP) model implies high values for these correlations, they are much weaker in the data. They extend the standard model to include a stochastic value of worker's outside option (home production) and a time to build a vacancy that help reconcile these discrepancies.[44] I can relate the stochastic value of home production to the state-dependent UI duration in my model since it implies that the outside options of workers evolve stochastically. As the model is this paper breaks down the tight link between output and labour productivity, a correlation between labour productivity and unemployment (−0.59 as shown in Table 8) is consequently very close to the data (−0.63) whilst a productivity-driven MP model would imply a very strong correlation. However, the labour productivity implied by both my model and that in Hagedorn and Manovskii (2011) is somewhat more highly correlated with the labour market tightness and vacancies than in the data. The model-implied correlations are nonetheless significantly smaller than one. The cyclical properties of match qualities are reported in Table 9. The average match quality is higher in post-1985 period during which the UI duration policy is more generous than in the pre-1985 period. As a higher match quality implies a longer duration of a match (since workers are less likely to find a better match), these results on match qualities are in line with empirical findings from Caliendo et al. (2013) who find a positive relationship between benefit duration and match stability. Furthermore, the correlations between match qualities and output

[43] Hagedorn and Manovskii (2011) show that a longer model period emphasises the time aggregation issues and lowers the correlation between unemployment and vacancies.

[44] Furthermore, they also show that some of the discrepancies is related to the data being used. Specifically, if the labour productivity series is constructed using the employment data from the Current Population Survey (CPS) instead of the Current Employment Statistics (CES), the correlations between labour productivity and other labour market variables become stronger.

Table 8
Moments not targeted.

Moment	Data	Baseline model	Moment	Data	Baseline model
std(u_{dur}) (weeks)	6.9941	5.3255 (2.5117)	corr(y, ρ_f)$_{pre85}$	0.8788	0.9282 (0.0323)
std(u^{UI})	0.1657	0.2136 (0.0271)	corr(y, ρ_f)$_{post85}$	0.8691	0.8337 (0.0633)
std(v)	0.1408	0.0781 (0.0044)	corr(y, ρ_x)$_{pre85}$	−0.8493	−0.7568 (0.0549)
std(u)/std(y)	8.7921	7.2199 (38.7559)	corr(y, ρ_x)$_{post85}$	−0.8098	−0.7417 (0.0451)
std(e)/std(y)	0.5412	0.6566 (3.754)	corr(y, u)$_{pre85}$	−0.8831	−0.9084 (0.0218)
std(w)/std(y)	0.3878	0.5167 (3.0179)	corr(y, u)$_{post85}$	−0.8915	−0.8946 (0.0395)
corr(y, ρ_f)	0.8009	0.9118 (0.0291)	corr(y, v)$_{pre85}$	0.8981	0.6655 (0.1011)
corr(y, ρ_x)	−0.8414	−0.7873 (0.0385)	corr(y, v)$_{post85}$	0.8693	0.5 (0.0873)
corr(y, u)	−0.8825	−0.8914 (0.0191)	corr(LP, u)	−0.633	−0.5932 (0.0351)
corr(y, v)	0.8850	0.6253 (0.0821)	corr(LP, v)	0.719	0.8823 (0.0313)
corr(u, v)	−0.8786	−0.3638 (0.0465)	corr(LP, θ)	0.703	0.8740 (0.0334)

Note: Standard errors are in parentheses. Variable descriptions are the same as Table 3. Empirical data for corr(LP, $\cdot$) are from Hagedorn and Manovskii (2011).

Table 9
Properties of the average match quality (m).

Moment	Baseline model	Moment	Baseline model
E(m)$_{pre85}$	0.8874	corr(y, m)$_{pre85}$	−0.3064
E(m)$_{post85}$	0.8884	corr(y, m)$_{post85}$	−0.5118
std(m)$_{pre85}$	0.0018	corr(u, m)$_{pre85}$	0.4081
std(m)$_{post85}$	0.0026	corr(u, m)$_{post85}$	0.5540

Note: m denotes an average match quality across all worker-firm matches in a given period.

as well as between match qualities and unemployment suggest that the average match quality is countercyclical and even more so when UI extensions become more generous.

4.10. Hazard rate of exiting unemployment

Despite the assumption that the unemployment duration is not part of the state variable, and, therefore, the job finding probability of a worker does not vary with her unemployment duration (but only with her UI status), the heterogeneity amongst unemployed workers in the model still has an implication for the duration-dependent job finding probabilities at the aggregate level. Contrary to a constant unemployment exit rate in a standard search and matching model (with no participation margins), the model in this paper can produce a realistic feature of the rate at which an unemployed worker finds a job by unemployment duration. Empirically, this rate is decreasing and usually convex in the time spent in unemployment. As depicted by Fig. 12, the model is able to replicate these properties because the heterogeneous job finding rates imply that those with a higher rate (the uninsured unemployed) leave unemployment faster and those with a lower rate (the insured unemployed) have longer unemployment duration. The average job finding rate, therefore, falls with the unemployment duration.

I present the hazard functions in two cases: (i) the insured unemployed workers remain insured throughout the unemployment spell, and (ii) the insured unemployed become uninsured with probability ϕ_H each period (implying the standard UI duration during normal times) as these are the lower and upper bounds for the realised maximum UI durations. The hazard rate is decreasing in the unemployment duration due to the changing composition of unemployed workers. Uninsured unemployed workers have a higher job finding rate and therefore exit unemployment faster than the insured type. With

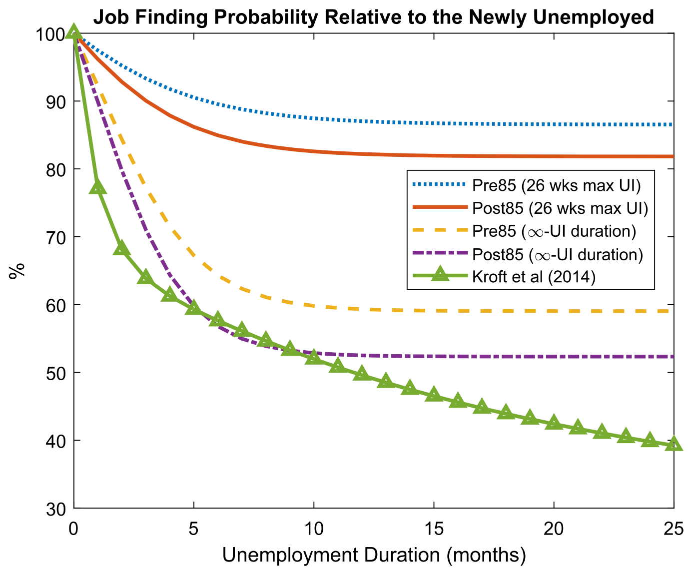

Fig. 12. Duration-dependent job finding probability (implied UI durations in parentheses).

time, unemployed workers are more represented by the insured type, the exit rate therefore falls with the unemployment duration and only becomes constant when there is no uninsured type left in the unemployment pool.

When compared to the data, Kroft et al. (2016) have estimated this hazard rate parametrically controlling for observable characteristics from the CPS data between 2002-2007. They find that the relative job finding rate (normalised to unity at zero duration) drops sharply during the first 8-10 months after which the rate becomes stable around 0.4-0.5. Their hazard function drops slightly faster than what this model can produce given that the insured unemployed remain insured throughout the spell (case (i)). However, when the stochastic UI exhaustion rate is taken into account (case (ii)), the model can only partially explain the drop in the hazard function during the first months of unemployment. The model's true performance lies between these two functions as the maximum UI durations can vary between 6 months to almost 2 years. This implies that the heterogeneity in the job finding rates by employment status can explain only partially the persistence of unemployment and its duration structure.

5. Conclusion

This paper is set out to quantify how much the increasingly generous UI duration policy during recessionary periods in the U.S. contributes to the substantial fall in the procyclicality of its labour productivity over the business cycle. The results are obtained from a search and matching model with stochastic UI duration, heterogeneous match quality, variable search intensity and on-the-job search. This model can produce over 40 percent of the empirical drop in the correlation between output and labour productivity. The countercyclical UI duration policy lowers the total match surpluses in bad times causing matches with low qualities to be unviable and, therefore, raises the average labour productivity while output is more negatively affected.

At the same time, this UI policy lowers the job search effort of the insured unemployed causing unemployment to be more persistent. Thus, it prolongs the UI extensions themselves and their effect on the correlation between output and labour productivity (since the UI policy is a function of the unemployment rate). As the UI duration policy is more generous after 1985, its effect via these two channels is stronger than that in the pre-1985 period which gives rise to the falling procyclicality of the labour productivity. A decomposition study shows that both channels are important in explaining this cyclicality change. Lastly, the model performs very well in producing key statistics in the labour markets, especially the insured unemployment rate over the business cycles.

Appendix A. Data

Both empirical and simulated (logged) data in this paper are detrended by using the Hodrick-Prescott (HP) filter with a smoothing parameter of 1600 for quarterly data and of 129600 for monthly data following Ravn and Uhlig (2002).

When necessary, monthly empirical series are converted to quarterly frequency by using a quarterly average except for the job finding rate and the job destruction rate whose quarterly series are obtained by iterating the law of motion for unemployment. The range of data (unless stated otherwise) is from January 1948 to June 2014. All series are seasonally adjusted.

A.1. Unemployment

Monthly data on unemployment level and labour force level are obtained from the Current Population Survey (CPS) provided by the Bureau of Labor Statistics (BLS), U.S. Department of Labor, from January 1948 to June 2014.[45] They do not include persons marginally attached to the labour force. The ratio of these two series forms the official definition of unemployment rate ('U3' as labelled by BLS).

A.2. Output and labour productivity

For output, I use the quarterly real GDP series provided by the Bureau of Economic Analysis (BEA), U.S. Department of Commerce, and I use the BLS quarterly series for non-farm output per job to represent the labour productivity.[46]

A.3. Transition rates

I obtain the monthly job finding rates and job destruction rates as is done in Shimer (2005) without correcting for time aggregation bias.[47] As converting the monthly turnover rates to quarterly ones by simply computing a quarterly average would overestimate the job finding rates and underestimate the job destruction rates, one should iterate the law of motion for monthly unemployment (u_t^{mo}) instead.

$$u_{t+1}^{mo} = (1 - \rho_{f,t}^{mo})u_t^{mo} + \rho_{x,t}^{mo}(1 - u_t^{mo}) \tag{11}$$

$$u_{t+2}^{mo} = (1 - \rho_{f,t+1}^{mo})u_{t+1}^{mo} + \rho_{x,t+1}^{mo}(1 - u_{t+1}^{mo}) \tag{12}$$

$$u_{t+3}^{mo} = (1 - \rho_{f,t+2}^{mo})u_{t+2}^{mo} + \rho_{x,t+2}^{mo}(1 - u_{t+2}^{mo}) \tag{13}$$

where $\rho_{f,t}^{mo}$ and $\rho_{x,t}^{mo}$ are respectively the monthly job finding and destruction rates at time t. Replacing u_{t+2}^{mo} in (13) with u_t^{mo} using (11) and (12) and setting $u_{t+1}^q \equiv u_{t+3}^{mo}$ and $u_t^q \equiv u_t^{mo}$, one can obtain[48]

$$u_{t+1}^q = (1 - \rho_{f,t}^q)u_t^q + \rho_{x,t}^q(1 - u_t^q) \tag{14}$$

where

$$\rho_{x,t}^q = \rho_{x,t+2}^{mo} + \rho_{x,t+1}^{mo}(1 - \rho_{x,t+2}^{mo} - \rho_{f,t+2}^{mo}) + \rho_{x,t}^{mo}(1 - \rho_{x,t+1}^{mo} - \rho_{f,t+1}^{mo})(1 - \rho_{x,t+2}^{mo} - \rho_{f,t+2}^{mo}) \tag{15}$$

$$\rho_{f,t}^q = 1 - \rho_{x,t} - \prod_{i=0}^{2}(1 - \rho_{x,t+i}^{mo} - \rho_{f,t+i}^{mo}) \tag{16}$$

A.4. UI duration policy

Data on UI extensions in the U.S. are provided by Employment and Training Administration (ETA), U.S. Department of Labor, which collects and summarises the Federal Unemployment Compensation Laws dating back to August 1935. There are 3 main types of UI durations: (i) the standard UI duration of 26 weeks, (ii) the automatic extension programme that is triggered by the state unemployment rate (either total, insured or both) called "Extended Benefits (EB)" programme which extends UI further by 13-20 weeks and (iii) the ad-hoc programmes that are often issued in the recessions and also triggered by the state unemployment rate providing additional UI ranging from 13 to 53 weeks.[49] The maximum duration of unemployment benefits in the U.S. is shown chronologically in Fig. 3 where I sum together all types of UI durations. Apart from the early 1980s recessions, the extended UI duration has been steadily increasing throughout the 1948-2014 period with its highest level at 99 weeks during the Great Recession.

Appendix B. Expressions for optimal search intensity and match surplus

Given the Bellman equations for the three types of workers $\{e, UI, UU\}$, we can take the first derivative to find the optimal search effort for these workers. The first order conditions are as follows

[45] The series IDs are respectively LNS13000000 and LNS11000000.

[46] The series ID for labour productivity is PRS85006163.

[47] By correcting for the time aggregation bias, the destruction rates will be higher and closer to the BLS data. However, since Shimer (2005)'s correction means a newly unemployed worker has on average half a month to find a new job before being recorded as unemployed, one must also adjust the Bellman equations in a discrete-time model accordingly, otherwise the implied unemployment will be too high when the model period is longer than half a month.

[48] We could also obtain the quarterly series of unemployment rates by collecting the first monthly unemployment rate of every quarter as in Robin (2011) instead of averaging every 3 months. This does not change significantly the statistics reported in this paper.

[49] For a more detailed account, see the ETA website. Appendix B of Mitman and Rabinovich (2014) also provides a good summary.

$$\nu_e'(s^e(m;\omega)) = -\beta(1-\delta)M(1,\theta(\omega))E_{\omega'|\omega}\Big[\ldots \tag{17}$$
$$(1-\lambda)(1-F(m))\Big(WS^{e+}(m;\omega') - E_{m'|m'>m}[WS^{e+}(m';\omega')]\Big)$$
$$+\lambda E_{m'}\Big[(1-F(m'))(WS^{e+}(m';\omega') - E_{m''|m''>m'}[WS^{e+}(m'';\omega')])\Big]\Big]$$
$$\nu_u'(s^{UI}(\omega)) = \beta M(1,\theta(\omega)) \times$$
$$E_{m'\omega'|\omega}\Big[\max\{WS^{UI}(m';\omega'),0\} - \xi(1-\phi)US(\omega')\Big] \tag{18}$$
$$\nu_u'(s^{UU}(\omega)) = \beta M(1,\theta(\omega))E_{m'\omega'|\omega}\Big[\max\{WS^{UU}(m';\omega'),0\}\Big] \tag{19}$$

where $\nu_i'(s) = a_i(1+d_i)s^{d_i}$; $i \in \{e,u\}$ and $WS^{e+}(\cdot;\cdot) \equiv \max\{WS^e(\cdot;\cdot),0\}$.

The surplus from being insured (as opposed to uninsured) of unemployed workers is defined as

$$US(\omega) \equiv U^{UI}(\omega) - U^{UU}(\omega).$$

The expressions for the total surpluses of worker-firm matches given the workers' previous employment statuses (e, UI, UU) and the surplus of being insured unemployed are respectively:

$$S^e(m;\omega) = y_{mZ} - \nu_e(s^e(m;\omega)) - \tau - (1-\psi)(b+h-\nu_u(s^{UI}(\omega)))$$
$$-\psi(h-\nu_u(s^{UU}(\omega))) + \beta E_{\omega'|\omega}\Big[\ldots$$
$$(1-\delta)(1-\lambda)\Big((1-p^e(m;\omega)(1-F(m)))S^{e+}(m;\omega')\ldots$$
$$+p^e(m;\omega)(1-F(m))E_{m'|m'>m}[\mu S^{e+}(m';\omega')]\Big)$$
$$+(1-\delta)\lambda E_{m'}\Big[(1-p^e(m;\omega)(1-F(m')))S^{e+}(m';\omega')\ldots$$
$$+p^e(m;\omega)(1-F(m'))E_{m''|m''>m'}[\mu S^{e+}(m'';\omega')]\Big]$$
$$-(1-\psi)p^{UI}(\omega)E_{m'}[\mu S^{UI+}(m';\omega')]$$
$$-\psi p^{UU}(\omega)E_{m'}[\mu S^{UU+}(m';\omega')]$$
$$+(1-\psi)\Big(\phi + p^{UI}(\omega)(1-\phi)\xi\Big)US(\omega')\Big]$$
$$S^{UI}(m;\omega) = y_{mZ} - \nu_e(s^e(m;\omega)) - \tau - (1-\phi)(1-\xi)(b+h\nu_u(s^{UI}(\omega)))$$
$$-(1-(1-\phi)(1-\xi))(h-\nu_u(s^{UU}(\omega))) + \beta E_{\omega'|\omega}\Big[\ldots$$
$$(1-\delta)(1-\lambda)\Big((1-p^e(m;\omega)(1-F(m)))S^{e+}(m;\omega')\ldots$$
$$+p^e(m;\omega)(1-F(m))E_{m'|m'>m}[\mu S^{e+}(m';\omega')]\Big)$$
$$+(1-\delta)\lambda E_{m'}\Big[(1-p^e(m;\omega)(1-F(m')))S^{e+}(m';\omega')\ldots$$
$$+p^e(m;\omega)(1-F(m'))E_{m''|m''>m'}[\mu S^{e+}(m'';\omega')]\Big]$$
$$-(1-\phi)(1-\xi)p^{UI}(\omega)E_{m'}[\mu S^{UI+}(m';\omega')]$$
$$-\Big(1-(1-\phi)(1-\xi)\Big)p^{UU}(\omega)E_{m'}[\mu S^{UU+}(m';\omega')]$$
$$+\Big(1-\psi-(1-\phi)^2(1-\xi)(1-\xi p^{UI}(\omega))\Big)US(\omega')\Big]$$
$$S^{UU}(m;\omega) = y_{mZ} - \nu_e(s^e(m;\omega)) - \tau - (h-\nu_u(s^{UU}(\omega))) + \beta E_{\omega'|\omega}\Big[\ldots$$
$$(1-\delta)(1-\lambda)\Big((1-p^e(m;\omega)(1-F(m)))S^{e+}(m;\omega')\ldots$$

$$
\begin{aligned}
&+p^e(m;\omega)(1-F(m))E_{m'|m'>m}[\mu S^{e+}(m';\omega')]\Big)\\
&+(1-\delta)\lambda E_{m'}\Big[(1-p^e(m;\omega)(1-F(m')))S^{e+}(m';\omega')\ldots\\
&+p^e(m;\omega)(1-F(m'))E_{m''|m''>m'}[\mu S^{e+}(m'';\omega')]\Big]\\
&-p^{UU}(\omega)E_{m'}[\mu S^{UU+}(m';\omega')]+(1-\psi)US(\omega')\Big]
\end{aligned}
$$

$$
\begin{aligned}
US(\omega) = {}& b-\nu_u(s^{UI}(\omega))+\nu_u(s^{UU}(\omega))\\
&+\beta E_{\omega'|\omega}\Big[p^{UI}(\omega)\mu E_{m'}[S^{UI+}(m';\omega')]-p^{UU}(\omega)\mu E_{m'}[S^{UU+}(m';\omega')]\\
&+(1-\phi)\Big(1-\xi p^{UI}(\omega)\Big)US(\omega')\Big]
\end{aligned}
$$

where $S^{j+}(\cdot;\cdot)\equiv\max\{S^j(\cdot;\cdot),0\}$; $j\in\{e,UI,UU\}$.

Appendix C. Transition rates

Employment-to-unemployment (EU). The rate an employed worker of type m becomes unemployed and the average EU transition rate are respectively

$$
\rho_{x,t}(m)=\begin{cases}\delta & \text{if } S^e_{m,t+1}>0,\\ 1 & \text{otherwise}\end{cases}
$$

$$
\rho_{x,t}=\frac{\delta\sum_{\{m:S^e_{m,t+1}>0\}}e^{post}_{m,t}+\sum_{\{m:S^e_{m,t+1}\le 0\}}e^{post}_{m,t}}{e_t}
$$

$$
\begin{aligned}
\text{where } e^{post}_{m,t} = {}&(1-\lambda)(1-p^e_{m,t}+p^e_{m,t}F(m))e_{m,t}+(1-\lambda)f(m)\sum_{m'<m}p^e_{m',t}e_{m',t}\\
&+\lambda f(m)\sum_{m'}(1-p^e_{m',t}+p^e_{m',t}F(m))e_{m',t}+\lambda F(m)f(m)\sum_{m'}p^e_{m',t}e_{m',t}
\end{aligned}
$$

denotes employed workers with match productivity m at the end of the period t.

Unemployment-to-employment (UE). The job finding rate for an unemployed worker of type $i=\{UI,UU\}$ and the average UE transition rate are respectively

$$
\rho^i_{f,t}=\sum_m\rho^i_{f,t}(m)f(m)
$$

$$
\rho_{f,t}=\frac{u^{UI}_t\rho^{UI}_{f,t}+u^{UU}_t\rho^{UU}_{f,t}}{u^{UI}_t+u^{UU}_t}
$$

$$
\text{where } \rho^i_{f,t}(m)=\begin{cases}p^i_t & \text{if } S^i_{m,t+1}>0,\\ 0 & \text{otherwise}\end{cases}
$$

Job-to-job transitions. The match-specific and the average job-to-job transition rates are respectively

$$
\begin{aligned}
\rho^{ee}_{m,t} = {}&(1-\delta)\Big((1-\lambda)p^e_{m,t}(1-F(m))E_{m'>m}[\mathbf{1}\{S^e_{m',t+1}>0\}]\\
&+\lambda\sum_{m'}p^e_{m,t}f(m')(1-F(m'))E_{m''>m'}[\mathbf{1}\{S^e_{m'',t+1}>0\}]\Big)
\end{aligned}
$$

$$
\rho^{ee}_t=\frac{\sum_m\rho^{ee}_{m,t}e_{m,t}}{e_t}
$$

Table 10
Performance of the approximation method.

Percentage deviation (%)	Mean	S.E.
1st moment	0.5650	0.3953
2nd moment	0.4670	0.4499
3rd moment	3.6819	3.4767
4th moment	0.2009	0.2936

Appendix D. Performance of the approximation method

Table 10 reports the average percentage deviations (in absolute value) of the 1st, 2nd, 3rd and 4th moments of the approximated distribution of employed workers over the match quality from the distributions obtained from the simulation. The method described in the Model section delivers distributions that are less than 1% different in terms of the 1st, 2nd and 4th moments from the actual distributions found in the simulation. However, it generates the 3rd moment that is more than 3% different from its counterpart since the skewness is more sensitive to the cut-offs in the distributions coming from endogenous destructions.

References

Acemoglu, Daron, Shimer, Robert, 2000. Productivity gains from unemployment insurance. European Economic Review 44, 1195–1224.
Auray, Stéphane, Fuller, David L., Lkhagvasuren, Damba, 2019. Unemployment insurance take-up rates in an equilibrium search model. European Economic Review 112 (C), 1–31.
Berger, David, 2018. Countercyclical restructuring and jobless recoveries. https://drive.google.com/open?id=1k4ktM09ew7bPYfiBBOoT9jmZVHEtK8_0.
Caliendo, Marco, Tatsiramos, Konstantinos, Uhlendorff, Arne, 2013. Benefit duration, unemployment duration and job match quality: a regression-discontinuity approach. Journal of Applied Econometrics 28 (4), 604–627.
Çenesiz, M. Alper, Guimarães, Luís, 2019. Income effects and the cyclicality of job search effort. CEF.UP Working Papers 1803.
Christensen, Bent J., Lentz, Rasmus, Dale Mortensen, T., Neumann, George R., Werwatz, Axel, 2005. On-the-job search and the wage distribution. Journal of Labor Economics 23 (1), 31–58.
DeLoach, Stephen B., Kurt, Mark, 2013. Discouraging workers: estimating the impacts of macroeconomic shocks on the search intensity of the unemployed. Journal of Labor Research 34 (4), 433–454.
den Haan, Wouter J., Ramey, Garey, Watson, Joel, 2000. Job destruction and propagation of shocks. The American Economic Review 90 (3), 482–498.
Ehrenberg, Ronald G., Oaxaca, Ronald L., 1976. Unemployment insurance, duration of unemployment, and subsequent wage gain. The American Economic Review 66 (5), 754–766.
Faig, Miguel, Zhang, Min, Zhang, Shiny, 2012. Effects of extended unemployment benefits on labor dynamics. http://minzhangsufe.weebly.com/uploads/1/1/0/1/11014021/recession_depedent_ui_2012_12_14.pdf.
Fredriksson, Peter, Holmlund, Bertil, 2001. Optimal unemployment insurance in search equilibrium. Journal of Labor Economics 19 (2), 370–399.
Fujita, Shigeru, Ramey, Garey, 2012. Exogenous versus endogenous separation. American Economic Journal: Macroeconomics 4 (4), 68–93.
Galí, Jordi, van Rens, Thijs, 2014. The vanishing procyclicality of labor productivity. In: Warwick Economics Research Paper Series No. 1062.
Garin, Julío, Pries, Michael, Sims, Eric, 2016. Reallocation and the changing nature of economic fluctuations. https://www3.nd.edu/~esims1/gps_may_27_2016.pdf.
Gomme, Paul, Lkhagvasuren, Damba, 2015. Worker search effort as an amplification mechanism. Journal of Monetary Economics 75 (C), 106–122.
Gruber, Jonathan, 1997. The consumption smoothing benefits of unemployment insurance. The American Economic Review 87 (1), 192–205.
Hagedorn, Marcus, Manovskii, Iourii, 2011. Productivity and the labor market: comovement over the business cycle. International Economic Review 52 (3), 603–619.
Hagedorn, Marcus, Manovskii, Iourii, 2013. Job selection and wages over the business cycle. The American Economic Review 103 (2), 771–803.
Hagedorn, Marcus, Karahan, Fatih, Manovskii, Iourii, Mitman, Kurt, 2013. Unemployment benefits and unemployment in the great recession: the role of macro effects. NBER Working Paper No. 19499.
Katz, Lawrence F., Meyer, Bruce D., 1990. The impact of the potential duration of unemployment benefits on the duration of unemployment. Journal of Public Economics 41 (1), 45–72.
Kroft, Kory, Lange, Fabian, Notowidigdo, Matthew J., Katz, Lawrence F., 2016. Long-term unemployment and the great recession: the role of composition, duration dependence, and non-participation. Journal of Labor Economics 34 (S1), S7–S54.
Krusell, Per, Smith Jr., Anthony A., 1998. Income and wealth heterogeneity in the macroeconomy. Journal of Political Economy 106, 867–896.
Marimon, Ramon, Zilibotti, Fabrizio, 1999. Unemployment vs. mismatch of talents: reconsidering unemployment benefits. The Economic Journal 109, 266–291.
McConnell, Margaret M., Perez-Quiros, Gabriel, 2000. Output fluctuations in the united states: what has changed since the early 1980s? The American Economic Review 90 (5), 1464–1476.
McGrattan, Ellen R., Prescott, Edward C., 2012. The labor productivity puzzle. In: Ohanian, Lee E., Taylor, John B., Wright, Ian J. (Eds.), Government Policies and the Delayed Economic Recovery. Hoover Institution Press, pp. 115–154.
Mitman, Kurt, Rabinovich, Stanislav, 2014. Unemployment benefit extensions caused jobless recoveries!? PIER Working Paper 14-013.
Mitman, Kurt, Rabinovich, Stanislav, 2015. Optimal unemployment insurance in an equilibrium business-cycle model. Journal of Monetary Economics 71 (C), 99–118.
Moffitt, Robert, 1985. Unemployment insurance and the distribution of unemployment spells. Journal of Econometrics 28 (1), 85–101.
Moffitt, Robert, Nicholson, Walter, 1982. The effect of unemployment insurance on unemployment: the case of federal supplemental benefits. Review of Economics and Statistics 64 (1), 1–11.
Mortensen, Dale T., Pissarides, Christopher A., 1994. Job creation and job destruction in the theory of unemployment. The Review of Economic Studies 61 (3), 397–415.
Mukoyama, Toshihiko, Patterson, Christina, Şahin, Aysegül, 2018. Job search behavior over the business cycle. American Economic Journal: Macroeconomics 10 (1), 190–215.
Nagypál, Éva, 2005. On the extent of job-to-job transitions. http://faculty.wcas.northwestern.edu/~een461/Extent_job_to_job_09162005.pdf.

Ravn, Morten O., Uhlig, Harald, 2002. On adjusting the Hodrick-Prescott filter for the frequency of observations. Review of Economics and Statistics 84 (2), 371–380.
Robin, Jean-Marc, 2011. On the dynamics of unemployment and wage distributions. Econometrica 79 (53), 1327–1355.
Rouwenhorst, K. Geert, 1995. Asset pricing implications of equilibrium business cycle models. In: Cooley, Thomas F. (Ed.), Frontiers of Business Cycle Research. Princeton University Press, Princeton, NJ, pp. 294–330.
Rujiwattanapong, W. Similan, 2019. Unemployment dynamics and endogenous unemployment insurance extensions. Centre for Macroeconomics Discussion Paper CFM-DP2019-09.
Shimer, Robert, 2004. Search intensity. http://home.uchicago.edu/~shimer/wp/intensity.pdf.
Shimer, Robert, 2005. The cyclical behaviour of equilibrium employment and vacancies. The American Economic Review 95 (1), 25–49.
Yashiv, Eran, 2000. The determinants of equilibrium unemployment. The American Economic Review 90 (5), 1297–1322.