The Effect of Medical Re-Evaluations for Disability Insurance Recipients on Aggregate Employment Dynamics*

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Abstract

This paper studies the macroeconomic effects of a disability insurance (DI) policy that terminates benefits of DI recipients on a recession in 1981 and its recovery. I document several facts. First, in the US, the recovery in the employment rate of men from the 1981 recession was faster than any other recovery since 1965. Second, during the 1981 recession and at the beginning of its recovery, the number of DI applicants and recipients dropped while the numbers increased in all other recessions. This decrease is attributed to the fact that the most stringent medical re-evaluations for DI recipients occurred between 1981 and 1983. Medical re-evaluation is a policy that periodically terminates benefits of ineligible DI recipients. This paper claims that the most stringent medical re-evaluations for DI recipients affect the depth of the 1981 recession and the speed of its recovery. In order to quantify the effects, I build a general equilibrium business-cycle search and matching model with health, DI and unemployment insurance (UI) eligibility. Medical re-evaluations affect the number of people who search for jobs (direct effect) and job-finding probabilities for all unemployed people (general equilibrium effect). The overall effect of the policy depends on how much firms want to hire workers and the state of the economy. The main experiment shows that the change in stringency of medical re-evaluations during the 1981 recession made the recession deeper (by 1.0%-point) and the recovery faster (by 1.4%-point).

Keywords: Disability insurance, medical re-evaluation, aggregate employment dynamics, 1981 recession, unemployment insurance

JEL Classification Numbers: E24, E32, E60, H55, I38, J65

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1 Introduction

Social Security Disability Insurance (DI) is a rapidly growing social insurance program in the US that provides income support to workers with work limiting disabilities. Most DI applicants and recipients are not allowed to work and are not part of the labor force. In 2019, approximately 133 billion dollars were allocated to more than 8.4 million DI recipients. DI recipients comprised approximately 5.0% of the working population aged 25 to 64 years in 2019.

One of the main problems associated with the DI program is that it allows workers who do not have severe work limitations to remain in the program until they reach their full retirement age or they die.[1] Some DI applicants can be wrongly accepted into the program because of loopholes in initial screening, especially in the diagnosis of diseases related to musculoskeletal system and connective tissues (e.g., back pain) and mental disorders (e.g., depression). Moreover, the health conditions of DI recipients can improve while they are in the program (Moore, 2015). The Social Security Administration (SSA) conducts periodic medical re-evaluations[2] to identify ineligible DI recipients and terminate their benefits. A temporary policy change[3] in 1980 mandated 1.2 million DI recipients to undergo medical re-evaluations. Approximately 0.54 million DI recipients were removed from the program between 1981 and 1983 as a result of this policy change. The extent of terminations was considered substantial given the number of DI recipients (2.82 million) and the unemployed (6.38 million) in 1981, which comprised 2.6% and 4.1% of the working population, respectively.

This paper quantifies the macroeconomic effects of the policy change which results in a sizable number of influx of terminated DI recipients into the labor force. In particular, This

[1]According to Social Security Administration (SSA), the mains reasons for leaving the DI program were retirement (59.8%) and death (27.6%) in 2019.

[2]A formal name of the policy is Continuing Disability Reviews (CDRs). According to SSA, the frequency of CDRs can range from 6 months to 7 years, depending on the severity of the impairment and the likelihood of improvement.

[3]Before the Social Security Disability Amendments of 1980, medical re-evaluations were conducted only for selected DI recipients whose medical condition was expected to be improved. However, after the amendments, the Congress required SSA to conduct medical re-evaluations on all DI recipients at least once every three years except for DI recipients expected to be permanently disabled.

paper claims that the most stringent medical re-evaluations implemented for DI recipients affect the depth of recession in 1981 and the speed of its recovery based on the following facts. In the US, the recovery in the employment rate of men from the 1981 recession was faster than any other recovery since 1965. The number of DI applicants and recipients during the 1981 recession and at the beginning of its recovery dropped, whereas the numbers increased in all other recessions. This decrease is attributed to the fact that the most stringent medical re-evaluations for DI recipients enforced between 1981 and 1983.

More stringent medical re-evaluations can affect employment rates through both direct and general equilibrium channels. More stringent medical re-evaluation induces more people to look for jobs (direct effect) because more DI recipients are terminated and start to look for jobs while less people apply for DI. If job-finding probabilities are fixed, then the direct effect will increase the employment rate. However, the increase in the number of people who look for jobs results in changes in job-finding probabilities for all unemployed people (general equilibrium effect). Whether job-finding probabilities decrease or increase depends on how much firms want to hire workers and on the state of the economy. A firm's decision to post a vacancy depends on the following two effects. If more people look for jobs, then it is easier for firms to find workers. This increases a firm's incentive to post a vacancy. On the other hand, DI recipients are more likely to have lower productivity. Therefore, the inflow of terminated DI recipients into the unemployment pool increases the probability of firms meeting less productive workers. In sum, when more people look for jobs due to more stringent medical re-evaluations, firms face a trade-off between a higher probability of finding workers and a lower probability of meeting more productive workers. So, it is ambiguous whether a firm will post a vacancy. Consequently, the general equilibrium effect which is the change in job finding probabilities is also ambiguous. The overall effect of the change in stringency of the policy on employment rate will be determined by the direct effect and the general equilibrium effects.

I build a general equilibrium business-cycle search and matching model with health (in terms of work limitation), DI, and unemployment insurance (UI) eligibility to quantify the macroeconomic effect of medical re-evaluations on the 1981 recession and its recovery. In the model, after receiving health shocks, risk-neutral employed people can quit their jobs in order to apply for DI. Unemployed people first decide whether to apply for DI, and then, choose whether to search for jobs while collecting UI benefits if they are eligible for UI. DI applicants must wait for five months until the acceptance decision is made.[4] During this period, they can also search for jobs if they want, and collect UI benefits. They can be accepted for DI with some probability and, if accepted, start to collect DI benefits and do not search for jobs. DI recipients receive medical re-evaluations every period with some probability and their benefits can be terminated with some probability. Each firm hires only one worker. Workers who have different productivity compete in the same labor market and firms do not know who will be matched with them when they post vacancies. Therefore, a firm decides whether to post a vacancy based on the expected value of posting a vacancy, which depends on the distribution of unemployed people. Worker flows into and out of the DI program affect the distribution of unemployed people. In turn, it affects a firm's decision to post a vacancy and job finding probabilities. Lastly, after meeting workers, firms immediately learn the worker's productivity and health status, and wages are determined by Nash bargaining based on this information.

The model is calibrated to match key features of the US economy, including a distribution of health status among employed people, unemployed people, and DI recipients. I use the Panel Study of Income Dynamics (PSID), Current Population Survey (CPS), and public Social Security Administration (SSA) data in the calibration. A key feature of computation is that the model has aggregate productivity shocks and heterogeneous workers are randomly matched in the same labor market. Therefore, the measure of unemployed people is one of the aggregate state variables. Krusell-Smith (1998) approximation is used to solve for the model outside of the steady state. In this paper, the measure of unemployed people is replaced with the total number of employed people.

To determine the effect of the policy change during the 1981 recession, I perform an experiment which is similar to what happened during the 1981 recession. This is an unexpected

[4] There is a mandatory wait period that is required by SSA. DI applicants must be disabled for five months after their disability onset date before they start receiving DI benefits.

one-time increase in the frequency[5] of medical re-evaluations during a recession. The experiment shows that more frequent medical re-evaluations during the 1981 recession made the recession deeper and the recovery faster. When I compare the beginning and the trough of the recession, the employment rate is lower by 1.0 percentage points when the policy becomes more stringent. When I compare the start of the recovery and after 2 years from that, the employment rate is higher by 1.4 percentage points when the policy becomes more stringent.

This paper makes several contributions in terms of documentation of facts, model, and quantitative analysis. I document three facts from the U.S. data. First, I show that the recovery in the employment of men from the 1981 recession was faster than any other recovery since 1965. In literature, recoveries before 1990 are considered faster than those after 1990. However, when I look at the employment rate for men, only the recovery from the 1981 recession was faster than any other recovery since 1965. In this sense, the 1981 recession is unique. Second, during the 1981 recession and at the beginning of its recovery, the number of DI applicants and recipients dropped while the numbers increased in all other recoveries. This result is attributed to the fact the most stringent medical re-evaluations occurred between 1981 and 1983. The period 1981-1983 is unique in the sense that the stringency (in terms of both frequency and tightness[6]) of medical re-evaluations was significantly higher than that in other periods. The main change in stringency of the policy during this period was the dramatic increase in frequency, whereas tightness remained high throughout 1978 to 1983. Third, I provide evidence on the importance of medical re-evaluations. When the policy became more stringent, prospective DI applicants were more willing to look for jobs rather than to apply for DI. Drastic variations in frequency and tightness of medical re-evaluations allow us to learn the relation between the decisions for DI applications and the stringency of the policy. Many papers have studied how other DI policies[7] affect the behavior of people, yet the importance of the medical re-evaluation policy

[5]It is measured as a proportion of DI recipients who received medical re-evaluations in the given year. Therefore, it can be interpreted as a probability of receiving medical re-evaluations.

[6]It is measured as a probability that DI benefits were ceased conditional on the medical re-evaluation.

[7]I can group them into three; 1) a policy that makes DI applicants hard to enter the DI program, 2) a policy that affects the amount of DI benefits, and 3) a policy that makes DI recipients hard to maintain their eligibility. Most papers focus on the first two policies.

has been overlooked.

In terms of model, this paper makes two contributions. First, to the best of my knowledge, this is the first business-cycle model with both DI and UI. Second, in my model, all unemployed people, including those who do not have any work limitation can be affected by DI policies through changes in job-finding probabilities (general equilibrium effect). Although many have used empirical methods or structural life-cycle models to study the behavior of prospective DI applicants or of rejected DI applicants, no one has studied the effect of DI policies on people who do not have any work limitation. If the size of worker flow in and out of the DI program is not negligible, these movements can affect the job-finding probabilities for all unemployed people who look for jobs in the same labor market. This mechanism works in my model through general equilibrium effects. In addition, general equilibrium feedback effects are quantitatively relevant because DI applications are sensitive to changes in job-finding probabilities.

The quantitative contribution of this paper is twofold. First, I examine the role of medical re-evaluations on the 1981 recession and its fast recovery. No one has studied the link between the change in DI policies and the fast recovery from the 1981 recession. This paper examines the effect of the increase in frequency of medical re-evaluations during the 1981 recession on the recession and its recovery through 1) a direct effect, namely, an increase in the number of people who look for jobs, and 2) a general equilibrium effect, namely, a change in job-finding probabilities for all unemployed people. The experiment shows that more frequent medical re-evaluations during a recession lead to a deeper recession and a faster recovery. Second, I use the model to examine the effect of the extended length of time people collect UI benefits in the presence of DI. Without DI, the extended UI benefits decrease employment rate. This is because workers look for jobs less intensively[8] and firms have less incentives to hire workers due to higher wages resulting from higher outside options of workers[9]. However, in the presence of DI, the extended UI benefits could increase employment rates. This is because there is one more important channel in the presence of DI. The extended UI benefits induces more people

[8] See Nakajima (2012)

[9] See Hagedorn et at. (2019)

to look for jobs by delaying their DI applications until UI benefits are expired. The results of experiments imply that in the presence of DI, the extended UI benefits during recessions can expedite recoveries if the timing of extension is well designed considering the state of the economy.

This paper is related to several strands of literature on DI. In terms of policy, Moore (2015) examines the employment effect of terminated DI recipients after the 1996 removal of drug and alcohol addictions as qualifying conditions, and finds that the employment effect from the policy change was large. The policy reform in Moore (2015) is similar to that in my paper in the sense that it terminated a subset of DI recipients from the DI program. However, Moore (2015) uses empirical methods to study the employment effect only for terminated DI recipients. In my paper, DI policies affect all the unemployed, including people who have no work limitation, through a change in job-finding probabilities. In terms of models with DI, several papers have a structural life-cycle model with DI and search friction in the labor market for steady state analysis. Benitez-Silva et al. (2011) study the effect of a policy that induces DI recipients to return to work. Low and Pistaferri (2015) estimate the disability risks that individuals face and the parameters governing the DI program. Kitao (2014) builds a life-cycle model to investigate the effects of cash transfer and in-kind Medicare component of the DI system on the life-cycle pattern of employment. In aforementioned papers, job-finding probabilities are fixed because they do not model firms. In contrast, this paper builds a general equilibrium business-cycle search and matching model with DI, where DI application decisions are affected by changes in job-finding probabilities over the business cycle. This paper is also related to literature on the relationship between UI policies and DI applications. Mueller et al. (2016) identify the effect of UI exhaustion on DI application and find no evidence that expiration of UI benefits causes DI applications. Lindner and Nichols (2014) examine whether or not participating in temporary assistance programs, including UI, influences DI applications, and find evidence that increased access to UI benefits reduces DI applications. Rutledge (2013) empirically investigates the effect of UI extensions on DI applications, and whether UI eligibility, extension, and exhaustion affect the timing of DI applications. Rutledge (2013) finds that jobless individuals are significantly less likely to apply for DI during UI extensions, and significantly more likely to apply when UI is exhausted. My paper examines the role of extended UI in the presence of DI during a recession with a general equilibrium model where DI applications are affected by UI policies as well as changes in job-finding probabilities.

This paper proceeds as follows. Section 2 documents facts about the 1981 recession, its fast recovery, and medical re-evaluations. Section 3 describes the model and Section 4 presents the calibration. Section 5 shows the results of quantitative analysis. Lastly, Section 6 concludes.

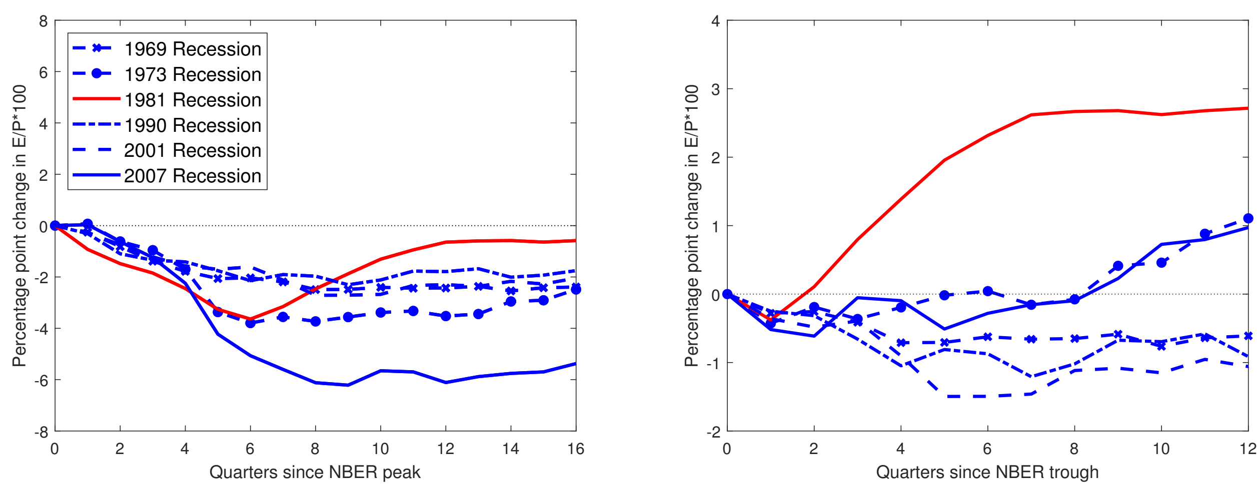
2 Facts

In this section, I document several facts about the 1981 recession, its fast recovery, and medical re-evaluations.

2.1 Fast recovery in the employment rates from the 1981 recession

Figure 1: Recessions and recoveries in the employment rate of men since 1965

(a) Recessions and recoveries (b) Recoveries



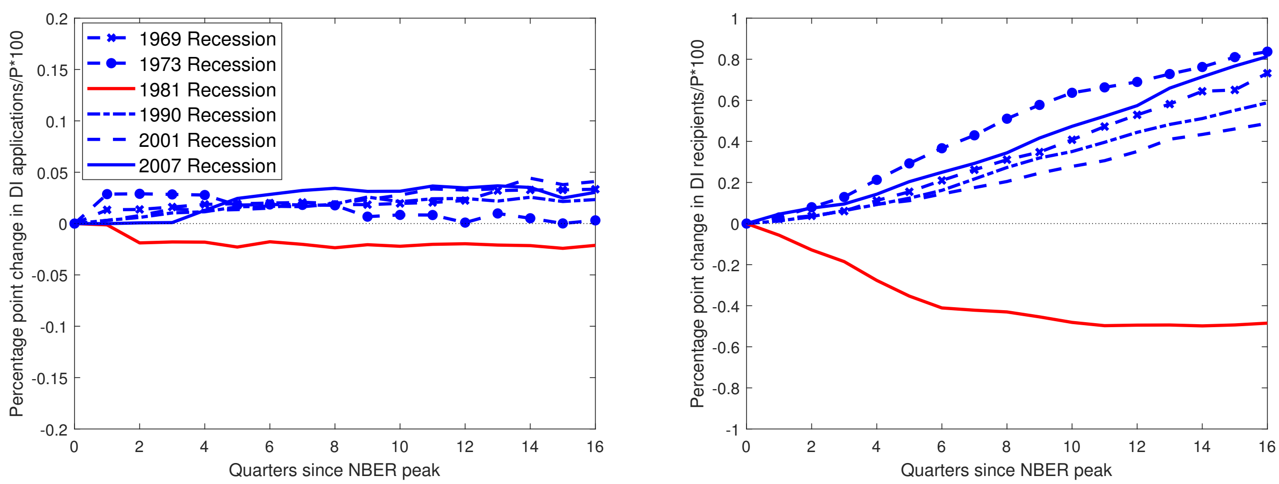
Note: Figure 1 shows percentage point changes in the employment rate of men (age 25-64). All series are computed from the monthly CPS, and they are quarterly averaged after seasonal adjustment.

In literature, recoveries before 1990 are considered faster than those after 1990. However, when I look at the employment rate for men, only the recovery from the 1981 recession was faster than any other recovery since 1965. In this sense, the recovery from the 1981 is unique. Figure 1(a) shows percent point changes in the employment rate[10] of men since NBER peak[11] and Figure 1(b) shows percent point changes in the employment rate of men since NBER trough. From Figure 1(b) we can clearly see that the recovery from the 1981 recession was significantly faster than others. The recovery from the 1981 recession is still fastest when I look at data including women as in Figure 12 and 13 in Appendix. The reason why I only use data for men in this paper is that woman's labor force participation steadily increased between 1970s and 1980s, which makes models more complicated.

2.2 Most stringent medical re-evaluation policy during 1981-1983

Figure 2: DI applicants and DI recipients

(a) DI applicants/Population (b) DI recipients/Population



Note: Figure 2 shows percentage point changes in DI applicants per population and DI recipients per population for men. All series are computed from the public Social Security Administration (SSA) data. Since the SSA do not publish DI application data by sex, DI applications for men are calculated with a total number of monthly DI applications and a share of men in DI awards each month.

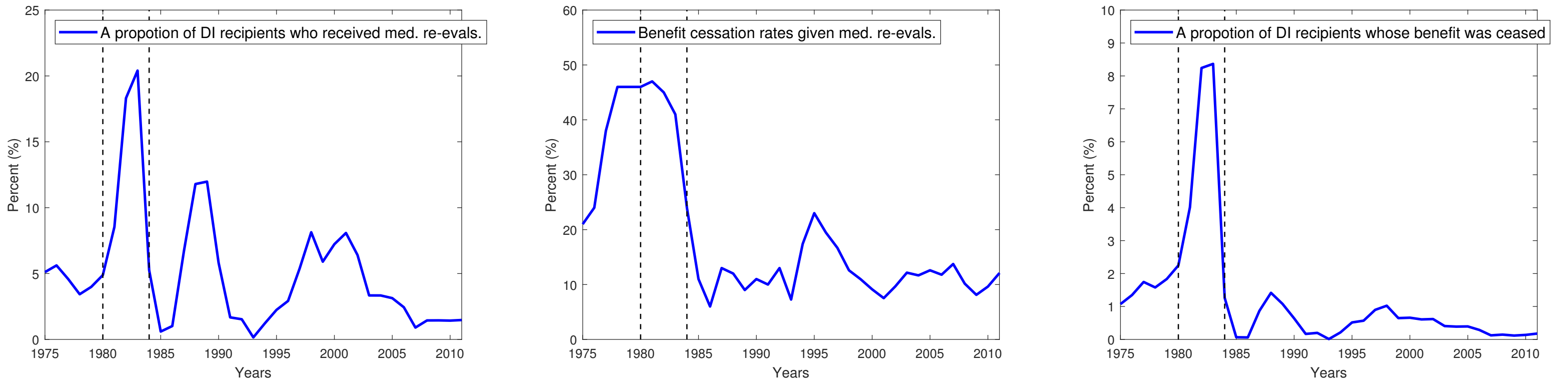
During the 1981 recession and at the beginning of its recovery, the number of DI applicants and recipients for men dropped while the numbers increased in all other recoveries as we can see in Figure 2. The number of DI recipients for men dropped from 3.78% of the working

[10]The definition of the employment rate in this paper is the employment-population ratio.

[11]I exclude the 1980 recession because it was shortly followed by the 1981 recession.

Figure 3: Three measures for stringency of medical re-evaluations

(a) Frequency (b) Tightness (c) Frequency and tightness



Note: Figure 3 shows three measures of stringency of medical re-evaluations. They are calculated with the data from GAO (1997) and SSA (2013).

population in 1980 to 3.14% of the working population in 1984. In this sense, the period 1981-1983 is unique and this is attributed to the fact that stringency of medical re-evaluations was significantly higher than that in other periods.

I define three different measures for stringency of medical re-evaluations. Figure 3(a) shows the frequency of medical re-evaluations, which is measured as a proportion of DI recipients who received medical re-evaluations in the given year. The annual frequency increased from 4.9% in 1980 to 20.4% in 1983 mainly due to the Social Security Disability Amendments of 1980. Before the amendments, medical re-evaluations were conducted only for selected DI recipients whose medical condition was expected to be improved. However, after the amendments, the Congress required SSA to conduct medical re-evaluations on all DI recipients at least once every three years except for DI recipients expected to be permanently disabled. Therefore, during 1981-1983 approximately 1.2 million medical re-evaluations were conducted and benefits of 0.5 million recipients were ceased.[12] This stringent medical re-evaluations led to public outcry which resulted in a nationwide moratorium on medical re-evaluations during 1983-1984 and the Social Security Disability Benefits Reform of 1984. In 1985, medical re-evaluations resumed on a gradual basis, employing the new medical improvement review standard mandated by the Congress in the 1984 Amendments. However, the frequency of medical re-evaluation

[12]Those numbers include both men and women.

varied based on budget availability afterward. Figure 3(b) shows the tightness of medical re-evaluations, which is measured as a probability that DI benefits were ceased conditional on the medical re-evaluation. The tightness was highest throughout 1978 to 1983. After the reform in 1984, tightness significantly dropped from 41% in 1983 to 11% in 1985 because the newly introduced medical review standard made SSA harder terminate the benefits of DI recipients. Finally, Figure 3(c) shows both the frequency and tightness of medical re-evaluations, which is measured as a a proportion of DI recipients whose benefit was ceased by the medical re-evaluation. We can see a big spike during 1981-1983, which shows the most stringent medical re-evaluations occurred during this period. The main change in stringency of the policy during this period was the dramatic increase in frequency, whereas tightness remained high throughout 1978 to 1983.

2.3 Importance of medical re-evaluations

Table 1: Correlations between stringency of med. re-evals. and behavior of the unemployed

1994-2006 (excluding recessions)	U w/ work limitation	U w/o work limitation
Corr(stringency of med re-evals, DI applications/pop)	-0.74	
Corr(stringency of med re-evals, Pr[U→E])	0.47	-0.02

Note: Stringency of medical re-evaluations denotes the third measure of stringency in Figure 3(c). DI applications are computed from the public SSA data. Transition probabilities from the unemployed to the employed by health status (self-reported work limitation) are calculated from the March CPS (men, 25-64). I choose the period 1994-2006 because there were major changes in the CPS in 1994. I exclude the recession periods because DI applications and the transition probabilities are sensitive to the recessions. However, when we include the recession periods, the signs and magnitudes are similar to the numbers in Table 1.

Many papers have studied how other DI policies[13] affect the behavior of people, yet the importance of the medical re-evaluation policy has been overlooked. I document that when the policy became more stringent, prospective DI applicants were more willing to look for jobs rather than to apply for DI. Drastic variations in frequency and tightness of medical re-evaluations allow us to learn the relation between the decisions for DI application and the stringency of the policy. Table 1 shows correlations between stringency of medical re-evaluations and behavior

[13]I can group them into three; 1) a policy that makes DI applicants hard to enter the DI program, 2) a policy that affects the amount of DI benefits, and 3) a policy that makes DI recipients hard to maintain their eligibility. Most papers focus on the first two policies.

of prospective DI applicants and of the unemployed. The correlation between the stringency of the policy and DI application per population is -0.74. The correlation between the policy and the transition probabilities from the unemployed to the employed for the unemployed who have work limitation is 0.47 whereas the correlation for the unemployed who have no work limitation is almost zero. This implies when the medical re-evaluations became more stringent, prospective DI applicants were more willing to look for jobs rather than to apply for DI.

3 Model

3.1 Environment

The model period is assumed to be a month. The economy consists of a continuum of risk-neutral workers and firms. The total measure of workers is normalized to one. Workers have an ex-ante heterogeneous individual productivity $x \in [\underline{x}, \overline{x}]$ which does not change over time. At the beginning of each period, workers receive a health shock (in terms of work limitation) γ. After receiving a health shock, employed people can quit in order to apply for DI. Unemployed people decide whether to apply for disability insurance (DI), and then choose whether to search for jobs while collecting unemployment insurance (UI) benefits b^U if they are eligible. DI applicants[14] must wait for 5 months until the acceptance decision is made. During this period, they can also search for jobs if they want,[15] and collect UI benefits.[16] They can be accepted with probability $\pi_a(\gamma)$ which depends on the level of work limitation. If they are accepted, then they start to collect DI benefits b^D and do not search for jobs. DI recipients can voluntarily leave the program to find jobs at the beginning of each period. If they choose

[14] People who have applied for DI

[15] Structural models in literature assume that DI applicants cannot search for jobs, even though there is no clear evidence for this assumption. The assumption about the behavior of DI applicants is quantitatively relevant because the incentives and timing of DI applications are affected by whether or not they can search for jobs while applying for DI. Therefore, in this paper, DI applicants have an option to search for jobs and collect UI benefits if they are eligible.

[16] In reality, if DI applicants collect UI benefits, it might lower the probability of being accepted to the DI program. But, I assume that collecting UI benefits during the 5-month waiting period does not affect the probability of being accepted to the DI program for simplicity.

to stay, then they receive medical re-evaluations with probability π_r at the end of the period.[17] and their DI benefits can be terminated with probability $\pi_t(\gamma)$. Each firm hires only one worker and firms do not know the worker's individual productivity and health status until they meet. Therefore, search is random in the sense that all types of workers compete in the same labor market and wages are determined by Nash Bargaining. I assume that wages does not depend on a worker's DI application status a, and months after DI application m for simplicity. The number of new matches is determined by the matching function $M = M(U, V)$. I can define the market tightness $\theta \equiv \frac{V}{U}$, job-finding probability for workers $p(\theta) \equiv \frac{M(U,V)}{U}$, and job-filling probability for firms $q(\theta) \equiv \frac{M(U,V)}{V}$. Firms can enter the market by posting a vacancy at the cost of κ.

3.2 Timing of the model

1. Aggregate labor productivity shocks and health shocks are realized
2. A worker's decision is made:

   - The employed decide to quit

   - The unemployed decide whether to apply for DI, then choose whether to search for jobs

   - DI recipients decide whether to leave the DI program to find jobs
3. Production takes place and vacancies are posted / search and matching occurs
4. DI acceptance decision is made and DI recipients are terminated through medical re-evaluations
5. The employed are exogenously separated

3.3 Worker's problem

The individual states of a worker are represented by (l, γ, a, m, e). $l \in \{E, U, D\}$ represents labor force status which includes the employed (E), the unemployed (U), and DI recipients

[17]For more appropriate analysis, the probability of receiving medical re-evaluations should depend on the health status when DI recipients were accepted to the DI program as in reality. Different probabilities can be reflected in the model, but there is no clear way to pin down these parameters due to lack of data and relevant target moments. For this reason, I assume that this probability is the same for every DI recipient in this paper.

(D) who are not in the labor force. $\gamma \in \{\gamma_n, \gamma_m, \gamma_s\}$ denotes the level of work limitation which lowers the individual productivity of the worker by γ. γ_n, γ_m, and γ_s denote no work limitation, moderate work limitation, and severe work limitation, respectively. Since DI applicants must wait for 5 months until the acceptance decision is made, I should keep track of DI application status $a \in \{0,1\}$, and months after DI application $m \in \{1,2,3,4,5\}$. Lastly, $e \in \{0,1\}$ indicates whether a worker is eligible for UI benefits or not.

The aggregate states of the economy are represented by (z, ψ) where z is an aggregate labor productivity and ψ is a measure of workers. Workers and firms should keep track of the measure of workers ψ because heterogeneous workers search for jobs in the same market and they are randomly matched to firms, which makes the job-finding probability $p(\theta(z,\psi))$ and job-filling probability $q(\theta(z,\psi))$ depend on the aggregate labor productivity z as well as on the measure of workers ψ. Since workers have a different individual productivity x, every value function is indexed by x.

Employed workers: Employed workers can quit in order to apply for DI at the beginning of each period.

$$W^x(E,\gamma,0,0,e;z,\psi) \quad = \quad \max\Big[\underbrace{W_c^x(E,\gamma,0,0,e;z,\psi)}_{work}, \underbrace{W^x(U,\gamma,0,0,e;z,\psi)}_{quit}\Big]$$

If they choose to work, they can be exogenously separated with probability χ at the end of the period and become unemployed. The stochastic process of the level of work limitation γ is governed by a transition probability matrix Π^γ. The employed without UI eligibility stochastically become eligible and the stochastic process is governed by a transition probability matrix Π_E^e. Wages depend on the individual productivity x, the level of work limitation γ, and UI eligibility e, which will be described later more in detail in the calibration section. I assume disutility from labor force participation $c_p(\gamma)$ for the employed and the unemployed who search for jobs.

$$
\begin{aligned}
W_c^x(E,\gamma,0,0,e;z,\psi) &= w^x(\gamma,e,\theta(z,\psi)) - c_p(\gamma) \\
\textit{(not separated)} &+ \beta E_{z,\gamma,e}\left[(1-\chi)W^x\left(E,\gamma',0,0,e';z',\psi'\right)\right. \\
\textit{(separated)} &+ \left.\chi W^x\left(U,\gamma',0,0,e';z',\psi'\right)\right] \\
s.t. & \\
& log\, z' = \rho\, log\, z + \varepsilon',\ \psi' = T(z,\psi),\ \gamma' = \Pi^{\gamma}(\gamma),\ e' = \Pi_E^e(e)
\end{aligned}
$$

Unemployed workers: Unemployed workers decide whether to apply for DI at an application cost of c_a at the beginning of the period.

$$
W^x(U,\gamma,0,0,e;z,\psi) = \max\Big[\underbrace{W_c^x(U,\gamma,0,0,e;z,\psi)}_{not\, apply},\underbrace{-c_a + W_a^x(U,\gamma,1,1,e;z,\psi)}_{apply\ for\ DI}\Big]
$$

Once they made the decision for DI application, they choose whether to search for jobs.

1) Unemployed workers who have not applied for DI

$$
W_c^x(U,\gamma,0,0,e;z,\psi) = \max\Big[\underbrace{W_{c,ns}^x(U,\gamma,0,0,e;z,\psi)}_{not\, search},\underbrace{W_{c,s}^x(U,\gamma,0,0,e;z,\psi)}_{search}\Big]
$$

If they do not search, then they just wait for one month.

$$
W_{c,ns}^x(U,\gamma,0,0,e;z,\psi) = \beta E_{z,\gamma,e}\left[W^x\left(U,\gamma',0,0,e';z',\psi'\right)\right]
$$

If they search for jobs, they collect UI benefits b^U if they are eligible even while applying for DI. If they find a job at the end of the period, they become employed. Otherwise, they remain unemployed. The unemployed with UI eligibility stochastically loose their eligibility and the stochastic process is governed by a transition probability matrix Π_U^e. $\mathbb{I}_{(e=1)}$ is an indicator function which has 1 if they are eligible for UI benefits.

$$
\begin{aligned}
W_{c,s}^x(U,\gamma,0,0,e;z,\psi) &= b^U(x,\gamma)\,\mathbb{I}_{(e=1)} - c_p(\gamma) \\
\textit{(find a job)} &+ \beta E_{z,\gamma,e}\left[p(\theta(z,\psi))W^x\left(E,\gamma',0,0,e';z',\psi'\right)\right. \\
\textit{(not find a job)} &+ \left.(1-p(\theta(z,\psi)))W^x\left(U,\gamma',0,0,e';z',\psi'\right)\right] \\
s.t. & \\
& log\, z' = \rho\, log\, z + \varepsilon',\ \psi' = T(z,\psi),\ \gamma' = \Pi^{\gamma}(\gamma),\ e' = \Pi_U^e(e)
\end{aligned}
$$

2) Unemployed workers who have applied for DI

$$W_a^x\left(U,\gamma,1,m\in\{1,2,3,4,5\},e;z,\psi\right) = \max\Big[\underbrace{W_{a,ns}^x\left(U,\gamma,1,m,e;z,\psi\right)}_{not\,search},\underbrace{W_{a,s}^x\left(U,\gamma,1,m,e;z,\psi\right)}_{search}\Big]$$

Before the 5th month of DI application, if they do not search, they just wait for one month as DI applicants.

$$W_{a,ns}^x\left(U,\gamma,1,m\in\{1,2,3,4\},e;z,\psi\right) = \beta E_{z,\gamma,e}\left[W_a^x\left(U,\gamma^{'},1,m+1,e^{'};z^{'},\psi^{'}\right)\right]$$

At the 5th month of DI application, if they are accepted, they become DI recipients. Otherwise, they remain unemployed.

$$\begin{aligned}
W_{a,ns}^x\left(U,\gamma,1,m=5,e;z,\psi\right) &= \\
(accepted) &\quad \beta E_{z,\gamma}\left[\pi_a(\gamma)\,W^x\left(D,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)\right. \\
(not\,accepted) &\quad + \left.(1-\pi_a(\gamma))\,W^x\left(U,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)\right]
\end{aligned}$$

Before the 5th month of DI application, if they search and find a job at the end of the period, they become employed or keep waiting for the decision. Otherwise, they remain DI applicants.

$$\begin{aligned}
W_{a,s}^x\left(U,\gamma,1,m\in\{1,2,3,4\},e;z,\psi\right) &= b^U(x,\gamma)\,\mathbb{I}_{(e=1)}-c_p(\gamma) \\
(find\ a\ job) &\quad + \beta E\left[p\left(\theta(z,\psi)\right)\max\left[W^x\left(E,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right),W_a^x\left(U,\gamma^{'},1,m+1,e^{'};z^{'},\psi^{'}\right)\right]\right. \\
(not\ find\ a\ job) &\quad + \left.\left(1-p\left(\theta(z,\psi)\right)\right)W_a^x\left(U,\gamma^{'},1,m+1,e^{'};z^{'},\psi^{'}\right)\right] \\
s.t.& \\
&\quad log\,z^{'}=\rho\,log\,z+\varepsilon^{'},\ \psi^{'}=T(z,\psi),\ \gamma^{'}=\Pi^{\gamma}(\gamma),\ e^{'}=\Pi_U^e(e)
\end{aligned}$$

At the 5th month of DI application, if they are accepted and find a job at the same time, they choose whether to become employed or DI recipients. If they are accepted but they do not get a job, they become DI recipients. If they are not accepted but find a job, they become employed. Lastly, if they are not accepted and do not find a job, they remain unemployed.

$$
\begin{aligned}
W_{a,s}^{x}\left(U,\gamma,1,5,e;z,\psi\right) &= b^{U}\left(x,\gamma\right)\mathbb{I}_{(e=1)}-c_{p}\left(\gamma\right)\\
\textit{(accepted \& find a job)} &+ \beta E\left[\pi_{a}\left(\gamma\right)p\left(\theta\left(z,\psi\right)\right)\max\left[W^{x}\left(E,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right),W^{x}\left(D,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)\right]\right.\\
\textit{(accepted \& not find a job)} &+ \pi_{a}\left(\gamma\right)\left(1-p\left(\theta\left(z,\psi\right)\right)\right)W^{x}\left(D,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)\\
\textit{(not accepted \& find a job)} &+ \left(1-\pi_{a}\left(\gamma\right)\right)p\left(\theta\left(z,\psi\right)\right)W^{x}\left(E,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)\\
\textit{(not accepted \& not find a job)} &+ \left.\left(1-\pi_{a}\left(\gamma\right)\right)\left(1-p\left(\theta\left(z,\psi\right)\right)\right)W^{x}\left(U,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)\right]\\
&s.t.\\
&\quad log\,z^{'}=\rho\,log\,z+\varepsilon^{'},\;\psi^{'}=T\left(z,\psi\right),\;\gamma^{'}=\Pi^{\gamma}(\gamma),\;e^{'}=\Pi_{U}^{e}(e)
\end{aligned}
$$

DI recipients: DI recipients decide whether to stay in the DI program or voluntarily leave it to find jobs at the beginning of the period.

$$
W^{x}\left(D,\gamma,0,0,e;z,\psi\right) = \max\Big[\underbrace{W_{c}^{x}\left(D,\gamma,0,0,0;z,\psi\right)}_{stay\,in\,DI},\underbrace{W^{x}\left(U,\gamma,0,0,e;z,\psi\right)}_{leave\,DI}\Big]
$$

If they choose to stay, they do not search for jobs while collecting DI benefits b^{D}. At the end of the period, they receive medical re-evaluations with probability π_{r} , and conditional on the medical re-evaluation, their benefit can be terminated with probability $\pi_{t}\left(\gamma\right)$. Once they start to collect DI benefits, they loose their UI eligibility with probability 1.

$$
\begin{aligned}
W_{c}^{x}\left(D,\gamma,0,0,0;z,\psi\right) &= b^{D}\left(x\right)\\
\textit{(terminated)} &+ \beta E_{z,\gamma}\left[\pi_{r}\pi_{t}\left(\gamma\right)W^{x}\left(U,\gamma^{'},0,0,0;z^{'},\psi^{'}\right)\right.\\
\textit{(not terminated)} &+ \left.\left(1-\pi_{r}\pi_{t}\left(\gamma\right)\right)W^{x}\left(D,\gamma^{'},0,0,0;z^{'},\psi^{'}\right)\right]\\
&s.t.\\
&\quad log\,z^{'}=\rho\,log\,z+\varepsilon^{'},\;\psi^{'}=T\left(z,\psi\right),\;\gamma^{'}=\Pi^{\gamma}(\gamma)
\end{aligned}
$$

If they choose to leave the program, they become unemployed.

3.4 Firm's problem

The individual states of a firm are represented by (γ, e) and the aggregate states are represented by (z, ψ). Each firm hires only one worker. Firms do not know the worker's individual productivity and the level of work limitation until they meet.

Firms matched with (x,γ,e)-type workers: At the end of the period, a worker can be exogenously separated or endogenously separated by quitting. Firms take the worker's decision for quitting s' as given. If the worker is separated, the firm becomes unmatched.

$$\begin{aligned} J^{x}\left(\gamma,e;z,\psi\right) &= zx\left(1-\gamma\right)-w^{x}\left(\gamma,e,\theta\left(z,\psi\right)\right) \\ \text{(not separated)} &+ \beta E\left[\left(1-\chi\right)\left(1-s^{'}\right)J^{x}\left(\gamma^{'},e^{'};z^{'},\psi^{'}\right)\right. \\ \text{(separated)} &+ \left.\left(1-\left(1-\chi\right)\left(1-s^{'}\right)\right)V\left(z^{'},\psi^{'}\right)\right] \end{aligned}$$

$$\begin{aligned} & s.t. \\ & log\, z^{'}=\rho\, log\, z+\varepsilon^{'},\ \psi^{'}=T\left(z,\psi\right),\ \gamma^{'}=\Pi^{\gamma}(\gamma),\ e^{'}=\Pi_{E}^{e}(e) \\ & s^{'}=g_{q}^{x}\left(E,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)=\begin{cases} 1 & if\ W_{c}^{x}\left(E,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right)<W^{x}\left(U,\gamma^{'},0,0,e^{'};z^{'},\psi^{'}\right) \\ 0 & if\ otherwise \end{cases} \end{aligned}$$

Unmatched firms: Since firms do not know the worker's individual productivity x and the level of work limitation γ, they have to take into account a type distribution of the unemployed who search for jobs when they decide to enter the market.

$$\begin{aligned} V\left(z,\psi\right) &= -\kappa \\ \text{(matched)} &+ \beta\left[q\left(\theta\left(z,\psi\right)\right)\int E_{z,\gamma,e}\left[\left(1-s^{'}\right)J^{x}\left(\gamma^{'},e^{'};z^{'},\psi^{'}\right)\right]\frac{\psi_{s}\left(x,U,\gamma,a,m,e\right)}{\int\psi_{s}\left(x,U,\gamma,a,m,e\right)d(x,U,\gamma,a,m,e)}d(x,U,\gamma,a,m,e)\right. \\ \text{(not matched)} &+ \left.\left(1-q\left(\theta\left(z,\psi\right)\right)\right)E_{z}\left[V\left(z^{'},\psi^{'}\right)\right]\right] \\ & s.t. \\ & log\, z^{'}=\rho\, log\, z+\varepsilon^{'},\ \psi^{'}=T\left(z,\psi\right),\ \gamma^{'}=\Pi^{\gamma}(\gamma),\ e^{'}=\Pi_{U}^{e}(e) \\ & \psi_{s}\left(x,U,\gamma,a,m,e\right)=\mathbb{I}_{\left(g_{s}^{x}\left(U,\gamma,a,m,e;z,\psi\right)=1\right)}\psi\left(x,U,\gamma,a,m,e\right) \\ & g_{s}^{x}\left(U,\gamma,a,m,e;z,\psi\right)\quad isadecisionruleforsearchingforjobs \end{aligned}$$

Free entry condition: With the free entry condition $V\left(z,\psi\right)=0$, we have

$$\kappa = \beta q\left(\theta\left(z,\psi\right)\right)\int E_{z,\gamma,e}\left[\left(1-s^{'}\right)J^{x}\left(\gamma^{'},e^{'};z^{'},\psi^{'}\right)\right]\frac{\psi_{s}\left(x,U,\gamma,a,m,e\right)}{\int\psi_{s}\left(x,U,\gamma,a,m,e\right)d(x,U,\gamma,a,m,e)}d(x,U,\gamma,a,m,e)$$

where $\psi_{s}\left(x,U,\gamma,a,m,e\right)=\mathbb{I}_{\left(g_{s}^{x}\left(U,\gamma,a,m,e;z,\psi\right)=1\right)}\psi\left(x,U,\gamma,a,m,e\right)$

Note that the market tightness $\theta(z,\psi)$ depends on the aggregate labor productivity z as well as on the measure of workers ψ.

3.5 Nash bargained wages

Wages are determined by Nash bargaining problem.

$$w^x(\gamma,e,\theta(z,\psi)) \quad = \quad arg\max_w \left(W_c^x(E,\gamma,0,0,e;z,\psi) - W^x(U,\gamma,0,0,e;z,\psi)\right)^{\mu}\left(J^x(\gamma,e;z,\psi)\right)^{1-\mu}$$

Or equivalently,

$$w^x(\gamma,e,\theta(z,\psi)) \quad s.t. \quad (1-\mu)\left(W_c^x(E,\gamma,0,0,e;z,\psi) - W^x(U,\gamma,0,0,e;z,\psi)\right) = \mu\left(J^x(\gamma,e;z,\psi)\right)$$

I assume that wages do not depend on a worker's DI application status a, and months after DI application m for simplicity. μ denotes the bargaining weight of workers.

3.6 Equilibrium

Definition (Recursive Competitive Equilibrium): A recursive competitive equilibrium is a set of value functions for workers $W^x(l,\gamma,0,0,e;z,\psi)$, $W_c^x(l,\gamma,0,0,e;z,\psi)$, $W_{c,ns}^x(U,\gamma,0,0,e;z,\psi)$, $W_{c,s}^x(U,\gamma,0,0,e;z,\psi)$, $W_{a,ns}^x(U,\gamma,a,m,e;z,\psi)$, $W_{a,s}^x(U,\gamma,a,m,e;z,\psi)$, value functions for firms $J^x(\gamma,e;z,\psi)$, $V(z,\psi)$, decision rules for quitting $g_q^x(E,\gamma,0,0,e;z,\psi)$, applying for DI $g_a^x(U,\gamma,0,0,e;z,\psi)$, searching for jobs $g_s^x(U,\gamma,a,m,e;z,\psi)$, leaving the DI program $g_l^x(D,\gamma,0,0,e;z,\psi)$, the market tightness $\theta(z,\psi)$, wages $w^x(\gamma,e,\theta(z,\psi))$, and a law of motion for the measure $\psi' = T(z,\psi)$ such that:

1. Given the market tightness and wages, decision rules for workers solve the worker's problems.
2. The market tightness is consistent with the free entry condition.
3. Wages are the solutions to the Nash bargaining problem.
4. The law of motion for the measure is consistent with optimal decision rules and stochastic processes of z, γ, and e.

4 Calibration

I assume the following matching function, a variant of Haan et al. (2000)

$$M(u,v) = \phi_1 \frac{uv}{\left(u^{\phi_2} + v^{\phi_2}\right)^{1/\phi_2}}$$

I put an additional scale parameter ϕ_1 as in Wiczer (2015) because without the scale parameter it is difficult to match both the level of the job-finding probability and the elasticity of job-finding probabilities with respect to the market tightness in data. The transition probability matrix of UI eligibility for the employed Π_E^e and the unemployed Π_U^e are assumed to be

$$\Pi_E^e = \begin{bmatrix} 1-\pi_E^{0,1} & \pi_E^{0,1} \\ 0 & 1 \end{bmatrix}, \quad \Pi_U^e = \begin{bmatrix} 1 & 0 \\ \pi_U^{1,0} & 1-\pi_U^{1,0} \end{bmatrix}$$

The employed without UI eligibility stochastically become eligible with probability $\pi_E^{0,1}$ and the unemployed with UI eligibility stochastically lose their eligibility with probability $\pi_U^{1,0}$.

4.1 Predetermined parameters

I choose a monthly discount factor β of 0.9967 which implies that the annualized interest rate is 4%. The bargaining weight of workers is set at 0.50. The elasticity parameter in the matching function is set at 1.6 as in Schaal (2017). The monthly probability of losing UI eligibility for

Table 2: Predetermined parameters

Parameter	Description	Value	Remark
β	Monthly discount factor	0.9967	Annual interest rate = 4%
μ	Bargaining weight of workers	0.50	
ϕ_2	Elasticity parameter in the matching function	1.6	Schaal (2017)
$\pi_U^{1,0}$	Monthly prob. of losing UI eligibility for the unemployed	0.1538	Aver. duration of UI: 26 weeks[18]
π_r	Monthly prob. of receiving medical re-evaluations	0.0048	GAO (1997), SSA (2013)
$\pi_a(\gamma_n)$	Monthly prob. of acceptance for no work limitation	0.0000	Assumption
ρ	Persistence of monthly aggregate labor productivity	0.97	Hagedorn & Manovskii (2011)
σ_ϵ	Standard dev. of monthly aggregate labor productivity	0.006	Hagedorn & Manovskii (2011)
rr	The replacement rate of UI benefits	0.40	Shimer (2005)

[18]Given the probability $\pi_U^{1,0}$, the average duration of UI benefits is $\frac{1}{\pi_U^{1,0}}$.

the unemployed is set at 0.1583 which implies that the average length of time people collect UI benefits is 26 weeks. The monthly probability of receiving medical re-evaluations is set to 0.48% regardless of health status. I assume that workers who do not have work limitation cannot be accepted to the DI program. I use the same shock process for the monthly aggregate labor productivity as that in Hagedorn and Manovskii (2011). The amount of unemployment benefits $b^U(x,\gamma)$ is determined by the following equation.

$$b^U(x,\gamma) = rr \times w^x\left(\gamma, 1, \overline{\theta}\right)$$

The replacement rate of UI benefits rr is set at 0.40 as in Shimer (2005) and the steady state wage $w^x\left(\gamma, 1, \overline{\theta}\right)$ is used when I calculate the benefits. DI benefits $b^D(x)$ is calculated by the same formula as the Social Security benefits. First, I need to compute the Average Indexed Monthly Earnings (AIME) which is the average of past highest earnings up to 35 years. Since the model does not have a life-cycle structure, I assume that the AIME can be approximated by the steady state wage for people who do not have work limitation and have UI eligibility, which is the highest wage among x-type workers in the model

$$\text{Average Indexed Monthly Earnings (AIME)} \equiv w^x\left(\gamma_n, 1, \overline{\theta}\right)$$

Based on the AIME, I compute the Primary Insurance Amount (PIA) by the following formula.

$$\text{PIA} = \begin{cases} 0.9 \times \text{AIME} & if\ \text{AIME} \leq \$297 \\ \$267.30 + 0.32 \times (\text{AIME} - \$297) & if\ \$297 < \text{AIME} \leq \$1,790 \\ \$745.06 + 0.15 \times (\text{AIME} - \$1,790) & if\ \$1,790 < \text{AIME} \end{cases}$$

I use the bend points in 1986 because every nominal wage in the calibration is discounted by the Consumer Price Index (CPI) given the base year 1986. Finally, the PIA is capped by the maximum amount of benefits which depends on the PIA. I also use the bend points in 1986.

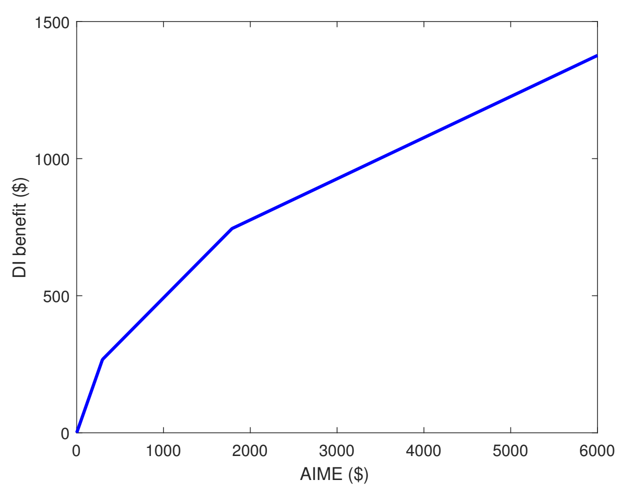
$$\text{Maximum amount of benefits} = \begin{cases} 1.5 \times \text{PIA} & if\ \text{PIA} \leq \$379 \\ \$568.50 + 2.72 \times (\text{PIA} - \$379) & if\ \$379 < \text{PIA} \leq \$548 \\ \$1,028.18 + 1.34 \times (\text{PIA} - \$548) & if\ \$548 < \text{PIA} \leq \$714 \\ \$1,250.62 + 1.75 \times (\text{PIA} - \$714) & if\ \$714 < \text{PIA} \end{cases}$$

Therefore, the DI benefits $b^D(x)$ in this paper can be expressed by

$$b^D(x) = \min[\text{PIA}, \text{Maximum amount of benefits}]$$

Figure 4 summarizes the relation between the AIME and DI benefits in the model.

Figure 4: Average Indexed Monthly Earnings (AIME) and DI benefits in the model



4.2 Parameters estimated outside of the model

I define a discrete variable for health status (the level of work limitation) following Low and Pistaferri (2015). In the PSID, people are asked three different questions about their work limitation:

1. Do you have any physical or nervous condition that limits the type of work or the amount

of work you can do? (possible answers: yes / no)

: If the answer is yes, then interviewer asks the second question.

2. Does this condition keep you from doing some types of work? (possible answers: yes / no / can do nothing)

   : If the answer is yes or no, then interviewer asks the third question.

3. For what work you can do, how much does it limit the amount of work you can do? (possible answers: a lot / somewhat / just a little / not at all)

Table 3 shows how I define the level of work limitation based on the three questions above.

Table 3: Definition of the level of work limitation

	Answer to the 1st Q.	Answer to the 2nd Q.	Answer to the 3rd Q.
No work limitation	No	-	-
	Yes	Yes / no	Not at all
Moderate work limitation	Yes	Yes / no	Somewhat / just a little
Severe work limitation	Yes	Can do nothing	-
	Yes	Yes / no	A lot

The monthly transition matrix for health status is estimated from the PSID by using the discrete variable for work limitation in Table 3. Given the assumption that a shock process for work limitation is stable throughout a year, an annual transition matrix Π_A^γ can be directly estimated from the PSID for 1986-1992[19]. Once the annual transition matrix is estimated, it can be converted to the monthly transition matrix Π^γ such that $(\Pi^\gamma)^{12} = \Pi_A^\gamma$. Table 4 represents the estimated monthly transition matrix Π^γ. The health conditions of DI recipients can improve while they are in the program as noted in Moore (2015). 4.8% of people with moderate work limitation and 4.6% of people with severe work limitation show improvement in their health status in the following month. They are potentially subject to medical re-evaluations, resulting in the termination of DI benefits.

[19]Data for DI recipients along with other variables are only available for this period.

Table 4: Monthly transition matrix for health status

	No work limitation	Moderate work limitation	Severe work limitation
No work limitation	0.9955	0.0041	0.0004
Moderate work limitation	0.0483	0.9351	0.0166
Severe work limitation	0.0152	0.0310	0.9538

4.3 Parameters calibrated in the model

17 remaining parameters are calibrated to match key features of the US economy for 1986-1992 by using 17 target moments. 11 parameters among 17 parameters are related to health and the DI program: the penalty rate of productivity with moderate work limitation γ_m and severe work limitation γ_s, probability of acceptance for moderate work limitation $\pi_a(\gamma_m)$ and severe work limitation $\pi_a(\gamma_s)$, probability of termination given medical re-evaluation for no work limitation $\pi_t(\gamma_n)$, moderate work limitation $\pi_t(\gamma_m)$, and severe work limitation $\pi_t(\gamma_s)$, disutility from labor force participation for no work limitation $c_p(\gamma_n)$, moderate work limitation $c_p(\gamma_m)$, severe work limitation $c_p(\gamma_s)$, and DI application cost c_a. 6 remaining parameters are related to the labor market: exogenous separation rate χ, a minimum value of individual productivity $\underline{x}$, a maximum value of individual productivity $\overline{x}$, the scale parameter in the matching function ϕ_1, cost of posting vacancies κ, and probability of getting UI eligibility for the employed $\pi_E^{0,1}$.

4.3.1 Target moments

First, I use a distribution of labor force status (Table 5) and a distribution of health status among the employed, the unemployed, and DI recipients (Table 6). Table 7 shows the rest of

Table 5: Distribution of labor force status (2 target moments)

Employed/Population	Unemployed/Population	DI recipients/Population	Sum
0.917	0.049	0.034*	1

Note: Table 5 shows a distribution of labor force status for 1986-1992. The numbers of the employed, the unemployed, and population are calculated from the monthly CPS (men, 25-64). The number of DI recipients is calculated from the public SSA data. *: it is not used because the distribution of labor force status adds up to one.

Table 6: Distribution of health status by labor force status (6 targets moments)

	No work limitation	Moderate work limitation	Severe work limitation	Sum
Employed	0.935	0.055	0.010*	1
Unemployed	0.775	0.185	0.040*	1
DI recipients	0.148	0.189	0.663*	1

Note: Table 6 shows distribution of health status by labor force status for 1986-1992. The numbers are calculated from the PSID (men, 25-64). *: they are not used because the distribution of health status given a specific labor force status adds up to one.

Table 7: Other statistics (9 target moments)

Target	Value	Remark
New DI applicants/P×100	0.109	SSA, 1986:Q1-1992:Q4
Average prob. of termination given med. re-evals.	0.106	SSA, 1986:Q1-1992:Q4
Rate of wage drops with moderate work limitation	0.251	PSID, 1986-1992
Rate of wage drops with severe work limitation	0.450	PSID, 1986-1992
5 percentile of monthly wages	640	PSID, 1986-1992
95 percentile of monthly wages	5,861	PSID, 1986-1992
Average job-finding probability	0.429	Shimer's data, 1986:Q1-1992:Q4
Elasticity of job-finding prob. w.r.t the market tightness	0.300	Shimer (2007)
Share of the unemployed who receive UI benefits	0.362	Nakajima (2012)

Note: The average job-finding probability is computed with the data constructed by Robert Shimer as part of Shimer (2012)

target moments. The number of new DI applications per population is used to pin down the DI application cost. The penalty rates of productivity with work limitations can be determined by wage differences between people who have no work limitation and people who have work limitation. In order to pin down the minimum and maximum values of individual productivity, I use the 5 percentile of monthly wages and 95 percentile of monthly wages from the annual wages in the PSID. The average job-finding probability and the elasticity of job-finding probabilities with respect to the market tightness are used to pin down the scale parameter in the matching function and the cost of posting vacancies.

4.3.2 Calibrated parameters

Table 8 summarizes 17 calibrated parameters and Table 9 represents moments from data and the model. The model successfully matches most of the targets, but the distributions of health status by labor force status are relatively difficult to match.

Table 8: 17 parameters calibrated in the model

Parameter	Description	Calibrated value
γ_m	Penalty rate of productivity with moderate work limitation	0.282
γ_s	Penalty rate of productivity with severe work limitation	0.625
$\pi_a(\gamma_m)$	Prob. of acceptance for moderate work limitation	0.150
$\pi_a(\gamma_s)$	Prob. of acceptance for severe work limitation	0.810
$\pi_t(\gamma_n)$	Prob. of termination given med. re-evals. for no work limitation	0.420
$\pi_t(\gamma_m)$	Prob. of termination given med. re-evals. for moderate work limitation	0.180
$\pi_t(\gamma_s)$	Prob. of termination given med. re-evals. for severe work limitation	0.010
$c_p(\gamma_n)$	Disutility from labor force participation for no work limitation	1032
$c_p(\gamma_m)$	Disutility from labor force participation for moderate work limitation	1210
$c_p(\gamma_s)$	Disutility from labor force participation for severe work limitation	1425
c_a	DI application cost	1,950
χ	Exogenous separation rate	0.017
$\underline{x}$	Minimum value of individual productivities	2,070
$\overline{x}$	Maximum value of individual productivities	6,130
ϕ_1	Scale parameter in the matching function	0.538
κ	Cost of posting vacancies	2,113
$\pi_E^{0,1}$	Prob. of getting UI eligibility for the employed	0.006

Table 9: Calibration results: data vs. model

Target	Data	Model
Employed/Population	0.917	0.918
Unemployed/Population	0.049	0.049
New DI applicants/P×100	0.109	0.118
Proportion of no work limitation among the employed	0.935	0.929
Proportion of moderate work limitation among the employed	0.055	0.064
Proportion of no work limitation among the unemployed	0.775	0.737
Proportion of moderate work limitation among the unemployed	0.185	0.134
Proportion of no work limitation among DI recipients	0.148	0.150
Proportion of moderate work limitation among DI recipients	0.189	0.210
Average prob. of termination given med. re-evals.	0.106	0.107
Rate of wage drops with moderate work limitation	0.251	0.248
Rate of wage drops with severe work limitation	0.450	0.449
5 percentile of monthly wages	640	708
95 percentile of monthly wages	5,861	5,870
Average job-finding probability	0.429	0.430
Elasticity of job-finding prob. w.r.t the market tightness	0.300	0.302
Share of the unemployed who receive UI benefits	0.362	0.361

5 Quantitative results

5.1 Steady state equilibrium

In this section, I compare main statistics in the steady states under different DI and UI policies.

5.1.1 Comparison of statistics: more stringent DI policies

Table 10: Statistics in the steady states: more stringent DI policies

Variables	(1)	(2)	(3)	(4)[20]	(5)
Prob. of acceptance for no work lim.	0.0%	0.0%	0.0%	0.0%	0.0%
Prob. of acceptance for moderate work lim.	15.0%	15.0%	15.0%	12.0%	15.0%
Prob. of acceptance for severe work lim.	81.0%	81.0%	81.0%	64.8%	81.0%
Monthly frequency of med. re-evals.	0.48%	0.48%	1.61%	0.48%	0.48%
Prob. of termination for no work lim.	42.0%	100.0%	100.0%	42.0%	42.0%
Prob. of termination for moderate work lim.	18.0%	100.0%	100.0%	18.0%	18.0%
Prob. of termination for severe work lim.	1.0%	20.0%	20.0%	1.0%	1.0%
Amount of DI benefits	-	-	-	-	20% ↓
Employed/Population	0.918	0.921	0.925	0.920	0.926
Unemployed/Population	0.049	0.050	0.049	0.049	0.048
DI recipient/Population	0.032	0.030	0.026	0.031	0.026
New DI applicant/Population×100	0.118	0.119	0.121	0.115	0.117
Job-finding probability	0.430	0.429	0.429	0.430	0.429
Vacancies×100	6.692	6.706	6.714	6.680	6.709
Average monthly wages ($ in 1986)	3,498	3,494	3,487	3,495	3,485

Table 10 compares main statistics in the steady states under 5 different DI policies.

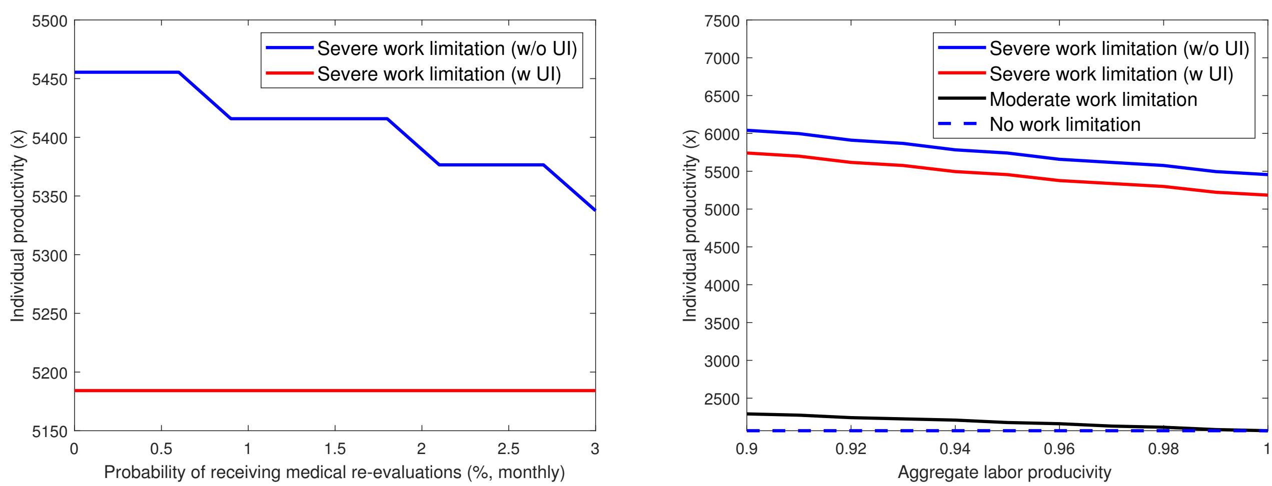
1. Baseline (1986-1992)
2. Tighter medical re-evaluations (average probability of termination: 44.3%)
3. Tighter and more frequent medical re-evaluations
4. Lower probability of acceptance
5. Less amount of DI benefits

[20] We drop probabilities of acceptance by 20% for DI recipients who have moderate and severe work limitations.

In general, more stringent DI policies result in less DI recipients and higher employment rates. However, the results for the number of DI applications are not trivial. The lower probability of acceptance and less amount of DI benefits induce less people to apply for DI. In contrast, under more stringent medical re-evaluations, ironically more people apply for DI in the steady state. When the medical re-evaluations become more stringent, workers have less incentives to apply for DI because of higher termination risks from the DI program. However, higher terminations from the DI program increase the number of unemployed people and the number of prospective DI applicants. The overall effect will depend on the magnitude of these conflicting effects. Given the calibration, when medical re-evaluations become more stringent, the latter effect dominates the former effect in the steady state. Consequently, slightly more people apply for DI whereas the number of DI recipients drops due to higher outflows from the DI program.

5.1.2 Cutoff productivity for DI applications

Figure 5: Cutoff productivity for DI applications



(a) Frequency of medical re-evaluations (b) Aggregate labor productivity

Figure 5 shows cutoff productivity for DI application in the steady state when the average probability of termination is 44.3%.[21] When individual productivities are lower than the

[21] I use this economy as a baseline in the main experiment in this paper

cutoff productivities, people apply for DI. In the steady state, only unemployed people who have severe work limitation apply for DI. Whether or not the unemployed are eligible for UI benefits is important for DI applications. People who are not eligible for UI benefits are more likely to apply for DI. Figure 5(a) shows how cutoff productivity changes as the probability of receiving medical re-evaluations changes. More frequent medical re-evaluations induce less people to apply for DI. Figure 5(b) shows how cutoff productivity changes as the aggregate labor productivity changes. As the aggregate labor productivity drops, more people apply for DI. In particular, people who have moderate work limitation start to apply for DI.

5.1.3 Comparison of statistics: more generous UI policies

Table 11: Statistics in the steady states: more generous UI policies

Variables	(1)	(2)	(3)	(4)	(5)
Duration of UI benefits	26 weeks[22]	26 weeks	26 weeks	52 weeks[23]	99 weeks[24]
Replacement rate	40%	50%	60%	40%	40%
Employed/Population	0.918	0.929	0.913	0.917	0.928
Unemployed/Population	0.049	0.045	0.061	0.050	0.048
DI recipient/Population	0.032	0.026	0.026	0.033	0.024
New DI applicant/Population×100	0.118	0.107	0.107	0.119	0.095
Monthly Job-finding rate	0.430	0.428	0.400	0.423	0.412
Vacancies×100	6.692	6.590	7.443	6.484	6.087
Average monthly wages ($ in 1986)	3498	3,482	3,479	3,506	3,494

Table 11 compares main statistics in the steady states under 5 different UI policies.

1. Baseline (1986-1992)
2. More amount of DI benefits (replacement rate: 50%)
3. More amount of DI benefits (replacement rate: 60%)
4. Longer length of time people collect UI benefits (52 weeks)
5. Longer length of time people collect UI benefits (99 weeks)

[22] In this case, the monthly probability of losing UI eligibility for the unemployed ($\pi_U^{1,0}$) is 0.133 (13.3%).
[23] In this case, the monthly probability of losing UI eligibility for the unemployed ($\pi_U^{1,0}$) is 0.077 (7.7%).
[24] In this case, the monthly probability of losing UI eligibility for the unemployed ($\pi_U^{1,0}$) is 0.040 (4.0%).

More generous UI policies give us non-trivial results for the employment rate. For example, the employment rate of the economy where the replacement rate is 50%, is higher than that of the baseline economy (40%). However, the employment rate of the economy where the replacement rate is 60%, is lower than that of the baseline economy. More generous UI policies affect the employment rate in two different ways. First, more people search for jobs without applying for DI, which will increase the employment rate. Second, it becomes more difficult for the unemployed to find jobs because more people look for jobs but firms have less incentives to hire workers due to higher wages resulting from higher outside options for workers. This will decrease the employment rate. The overall effects depend on the relative magnitude of these two effects. If the replacement rate is sufficiently high, then the latter effect outweighs the former effect. As a result, we have lower employment rates. In terms of the duration of UI, the employment rate of the economy where the maximum length of time people collect UI benefits is 52 weeks, is lower than that of the baseline economy (26 weeks). However, the employment rate of the economy where the maximum length of time is 99 weeks, is higher than that of the baseline economy. If the length of time is sufficiently longer, such as 99 weeks, the former effect dominates the latter effect and the employment rate can be higher than that of the baseline economy. In sum, more generous UI policies can lead to higher employment rates in the presence of DI as opposed to literature in which more generous UI policies generally decrease the employment rates due to less incentives for workers to search for jobs or less incentive for firms to post vacancies.

5.2 Equilibrium with aggregate labor productivity shocks

5.2.1 Krusell-Smith (1998) approximation

$$\kappa = \beta q\left(\theta\left(z,\psi\right)\right)\int E_{z,\gamma,e}\left[\left(1-s^{'}\right)J^{x}\left(\gamma^{'},e^{'};z^{'},\psi^{'}\right)\right]\frac{\psi_{s}\left(x,U,\gamma,a,m,e\right)}{\int\psi_{s}\left(x,U,\gamma,a,m,e\right)d(x,U,\gamma,a,m,e)}d(x,U,\gamma,a,m,e)$$

$$\text{where }\ \psi_{s}\left(x,U,\gamma,a,m,e\right)=\mathbb{I}_{\left(g_{s}^{x}\left(U,\gamma,a,m,e;z,\psi\right)=1\right)}\psi\left(x,U,\gamma,a,m,e\right)$$

Given that all unemployed people look for jobs in the same labor market, the market tightness $\theta(z,\psi)$ depends on the aggregate labor productivity z as well as on the measure of workers ψ as we can see in the free entry condition above. In this case, it is not possible to solve for the equilibrium with aggregate shocks outside of the steady state because the measure is an infinite dimensional state variable. Krusell and Smith (1998) approximate the equilibrium with aggregate shocks by replacing a measure with finite moments of the economy under the assumption of bounded rationality. Following their method, the measure ψ is replaced with the aggregate employment E in this paper. Therefore, the aggregate state variables in this economy are $\{z,E\}$ in stead of $\{z,\psi\}$. In order to predict the market tightness θ and the future value for the aggregate employment $E^{'}$, I assume simple log-linear prediction functions for the market tightness $\theta(z,E)$ and the aggregate employment $E^{'}$:

$$log(\theta) = b_{\theta,0} + b_{\theta,1}log(E) + b_{\theta,2}log(z)$$
$$log(E') = b_{E,0} + b_{E,1}log(E) + b_{E,2}log(z)$$

The details about the computation is described in the Appendix. The following is the converged prediction functions and their accuracies for the baseline model:

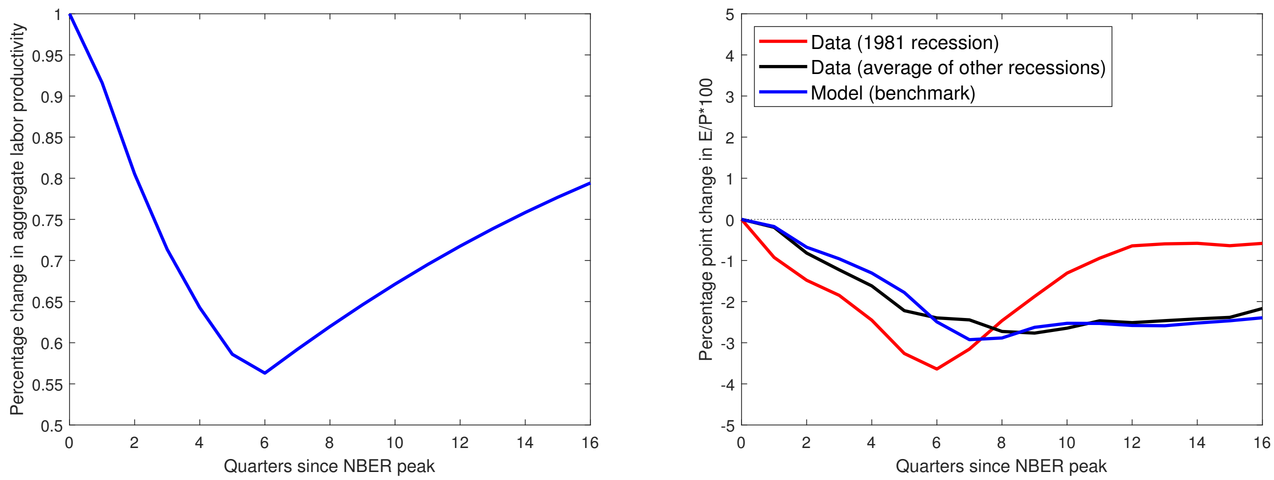
$$log(\theta) = 0.5340 + 0.1033\, log(E) + 0.8329\, log(z)\,,\ R^2 = 0.9524$$
$$log(E') = -0.0001 + 0.9993\, log(E) + 0.0015 log(z)\,,\ R^2 = 0.9987$$

5.2.2 Change in frequency of medical re-evaluation during a recession

To determine the effect of the policy change during the 1981 recession, I perform a simple experiment:[25] an unexpected one-time increase in the frequency of medical re-evaluations. Figure 6 shows a series of aggregate labor productivities (Figure 6(a)) to generate a benchmark recession (Figure 6(b)) which is the average of other recessions since 1965 except the 1981 and 2007 recessions. Given that aggregate labor productivity shocks cannot generate sufficient

[25]This experiment is not exactly the same as what happened during the 1981 recession. I simplify the experiment in order to clearly show how the policy change affects the recession and its recovery.

Figure 6: Aggregate labor productivity and paths of employment rates in the baseline recession

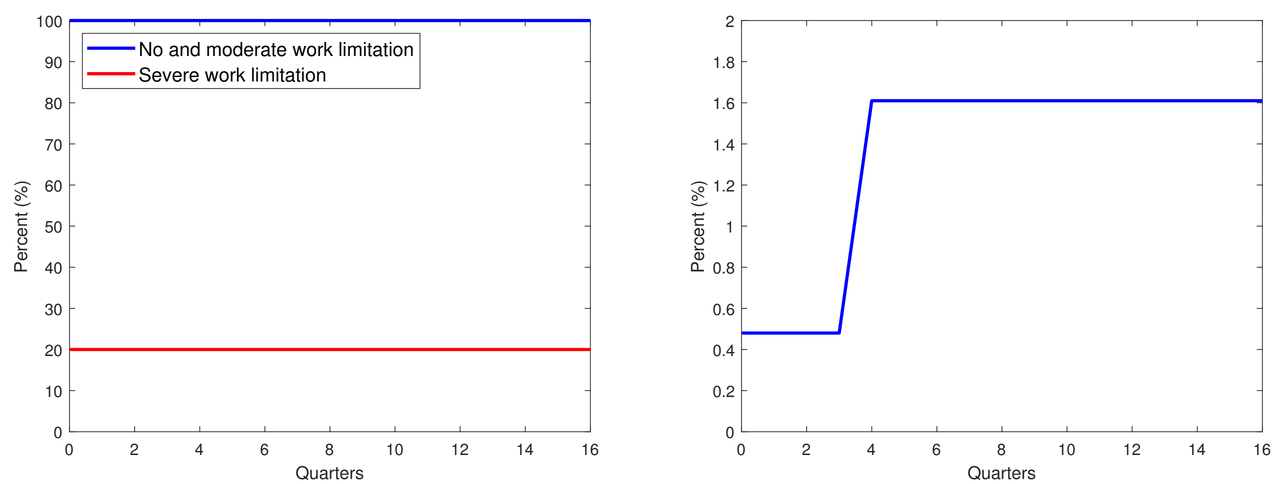


(a) Aggregate labor productivity

(b) Benchmark recession

Note: All series from the model are converted to quarterly series by averaging three consequent monthly series.

Figure 7: Inputs for the experiment: change in the frequency of med. re-evals during a recession

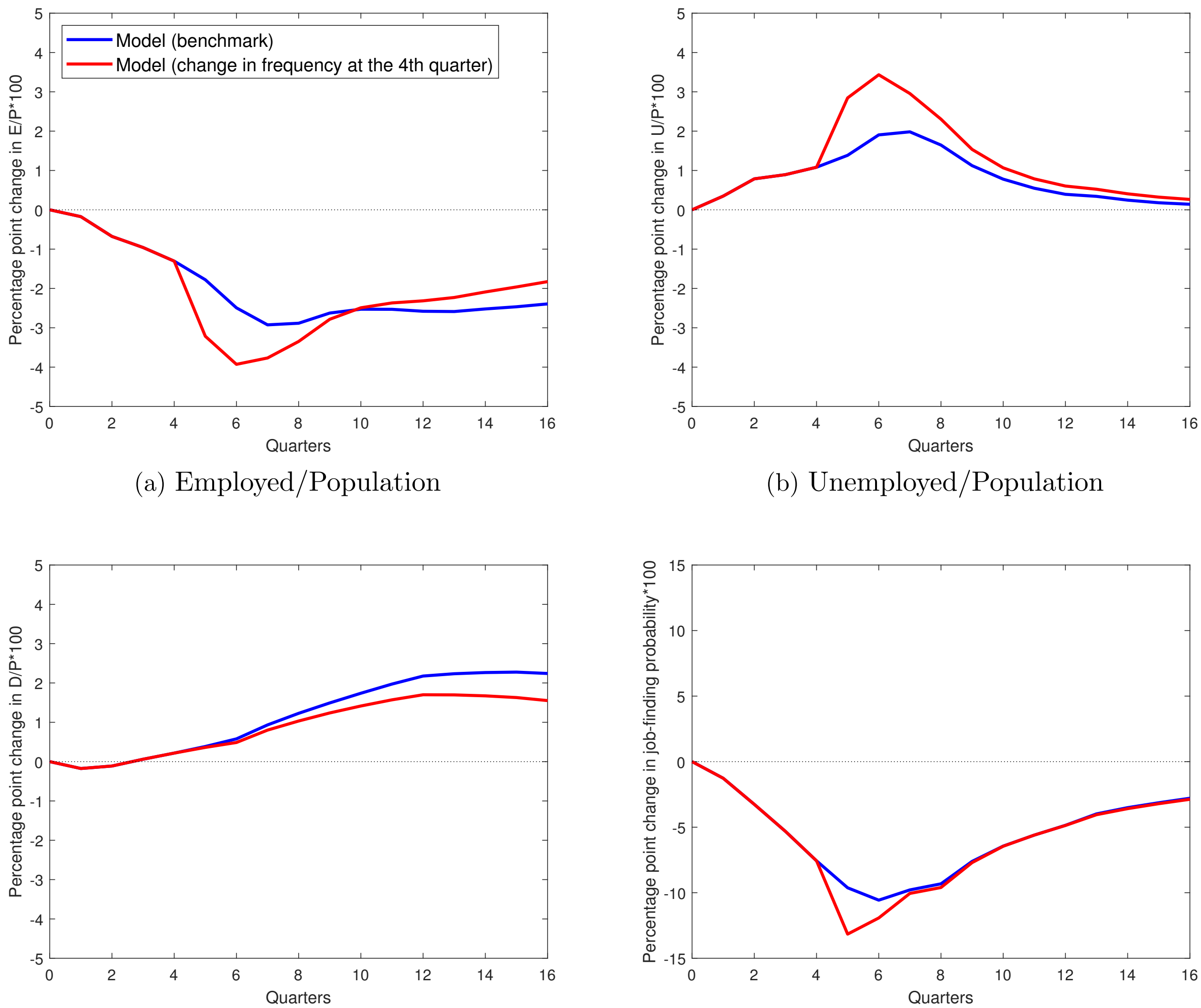


(a) Tightness of med. re-evals.

(b) Frequency of med. re-evals.

variations in unemployment and employment in search and matching models as noted in Shimer (2005), I need a big drop of aggregate labor productivities to generate an appropriate magnitude of the recession in data. Tightness for DI recipients who have no and moderate work limitation is set to 100%, and tightness for DI recipients who have severe work limitation is set to 20%. Given the distribution of DI recipients in the steady state, the average tightness of medical re-

Figure 8: Results: change in frequency of medical re-evaluations



(a) Employed/Population (b) Unemployed/Population

(c) DI recipients/Population (d) Job-finding probabilities

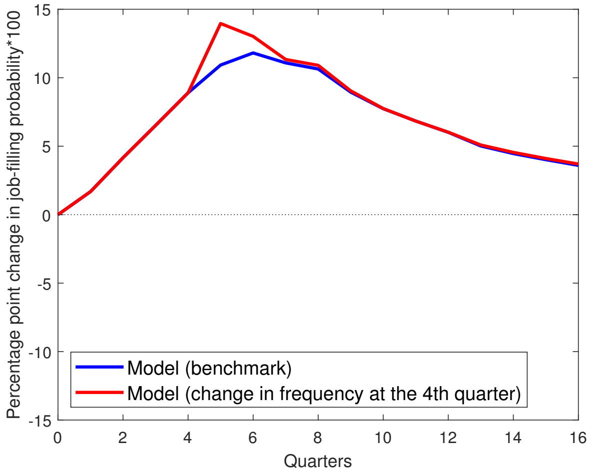
Note: All series from the model are converted to quarterly series by averaging three consequent monthly series.

evaluations is 44.3%, which is the average in data during 1981-1983. Given 44.3% of tightness of medical re-evaluations[26], I only change the frequency of medical re-evaluations from 0.48% to 1.61% (monthly frequency) at the 4th quarter after the onset of the recession.

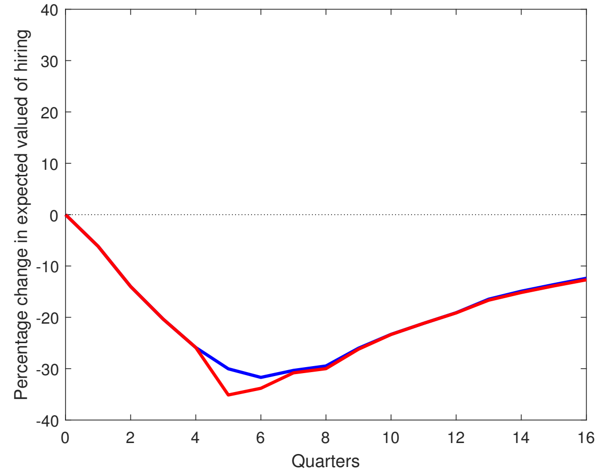
The start of the 1981 recession was 1981:Q3, and the trough was 1982:Q4. Since the frequency of medical re-evaluations was highest between 1982 and 1983, the policy change is assumed to have occurred in 1982:Q3, four quarters after the start of the recession. Figure 7

[26]This is the average for the period 1981-1983. There was no significant change in the tightness before and during the 1981 recession.

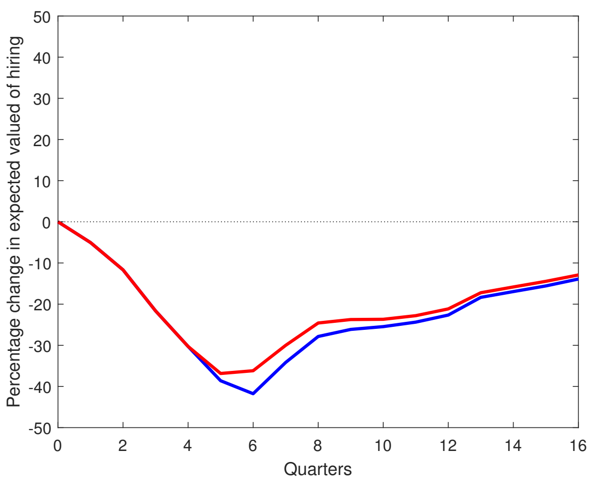
Figure 9: Results: change in frequency of medical re-evaluations (continued)



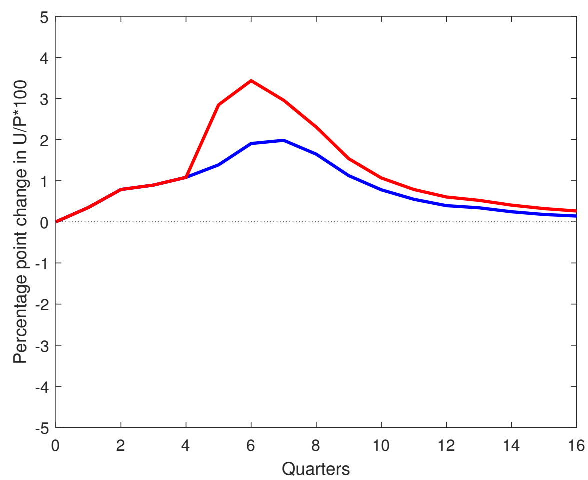
(a) Job-filling probabilities



(b) Expected value of hiring



(c) Vacancies



(d) Unemployed/Population

Note: All series from the model are converted to quarterly series by averaging three consequent monthly series.

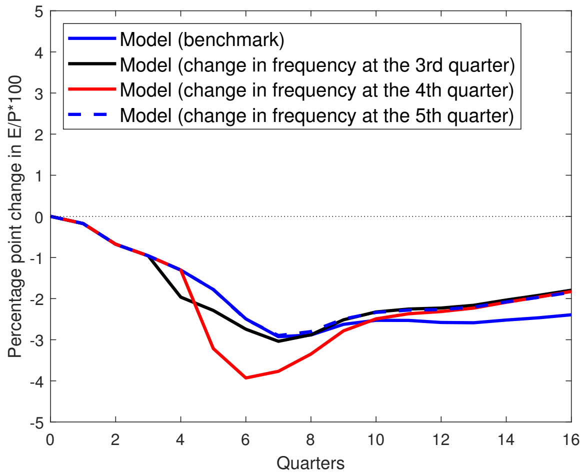
shows the inputs for the experiment. I assume that this policy change is unexpected and it occurs after the decisions of the workers are made in that period.

Figure 8 shows the main result for the experiment. As we can see Figure 8(a), the model generates a deeper recession and faster recovery afterward. When I compare the beginning and the trough of the recession, the employment rate is lower by 1.0 percentage points when the policy becomes more stringent. When I compare the start of the recovery and after 2 years from that, the employment rate is higher by 1.4 percentage points when the policy becomes more stringent. Note that the recovery in the model is not as fast as the one in the data. There might be other reasons for the faster recovery than medical re-evaluations, such as expansionary monetary policies and tax cuts during the Reagan administration.[27] Since the aggregate productivity measured as total factor productivity (TFP) or aggregate labor productivity is not that different across different recoveries as in Figure 15 in the Appendix, the difference in productivity during recoveries does not seem to be the main reason.

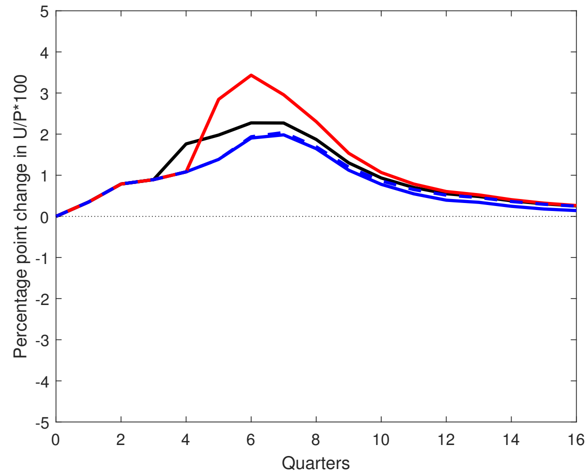
The main mechanism for the deeper recession and faster recovery in the model is as follows. Medical re-evaluations affect the number of people who search for jobs (direct effect) and job-finding probabilities for all unemployed people (general equilibrium effect). When the frequency unexpectedly increases at the 4th quarter, the number of unemployed people significantly increases as in Figure 8(b). The increase in the number of the unemployed results in a sharp decrease in job-finding probabilities as we can see in Figure 8(d). As more people look for jobs, the probability of firms meeting workers increases as in Figure 9(a). However, the expected value of hiring a worker decreases as in Figure 9(b) because the inflow of terminated DI recipients into the unemployment pool decreases the probability of meeting good (more productive) workers. Since the former effect slightly dominates the latter effect, firms post more vacancies compared to the economy where there is no change in the frequency of the policy. Although firms post more vacancies, the increase in the number of people who look for jobs outweighs the increase in the number of vacancies during the recession. Consequently, the job-finding probabilities drops as we can see in Figure 8(d). In sum, the effect of the drop in job-finding probabilities dominates the effect of the increase in the number of people who look for jobs. Therefore, the recession becomes deeper compared to the recession where no change in the frequency of the policy occurs. However, as the economy recovers, job-finding probabilities

[27] Aside from the other reasons like expansionary monetary policies and tax cuts during the Reagan administration, the model has a problem regarding a magnitude of the increase in DI recipients during the recession and its recovery as we can see in Figure 8(c). The number of DI recipients in the benchmark recession increases much more sharply compared to the one in data. This problem may be related to the Shimer puzzle. As we discussed before as in Figure 6(a), aggregate labor productivity shocks cannot generate sufficient variations in unemployment and employment in search and matching models. Therefore, we need a big drop of aggregate labor productivity to generate an appropriate magnitude of the recession in data. The problem is that more unemployed people apply for DI when the productivity drops as in Figure 5(b), and the big drop of aggregate labor productivities makes more unemployed people apply for DI in the model than in data.

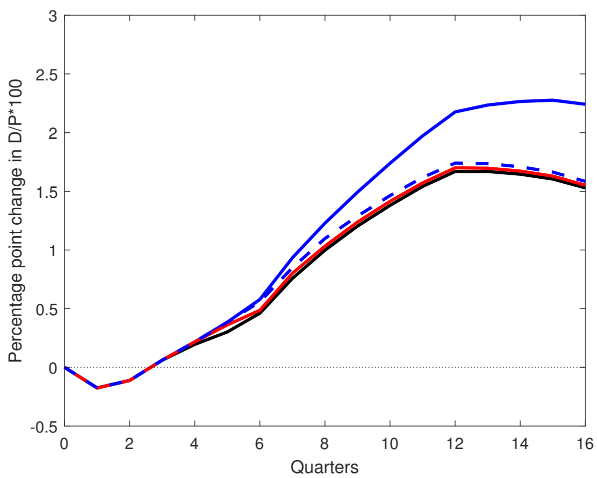
Figure 10: Results: change in frequency of medical re-evaluations (different timing)



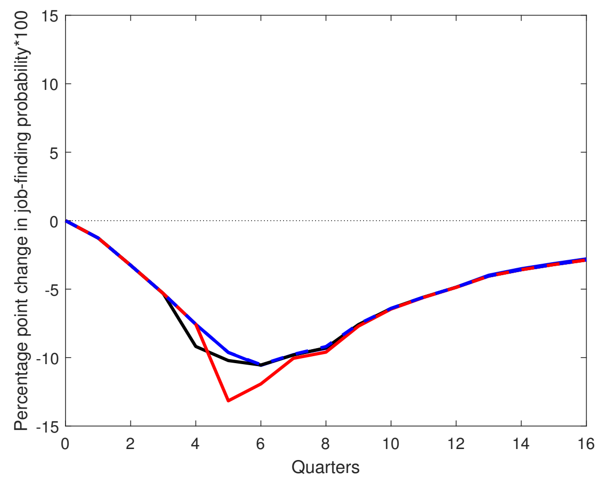
(a) Employed/Population



(b) Unemployed/Population



(c) DI recipients/Population



(d) Job-finding probabilities

Note: All series from the model are converted to quarterly series by averaging three consequent monthly series.

start to increase because more jobs are posted as we can see in Figure 8(d). Consequently, the effect of the increase in the number of people who look for jobs outweighs the effect of job-finding probabilities, which leads to a faster recovery.

The timing of changing in frequency is also relevant. Figure 10 shows the results for changes in frequency of medical re-evaluations at three different quarters. When the policy changes at the 3rd quarter after the onset of the recession, the drops in employment rates and job-finding probabilities are not large. When the policy changes at the 4th quarter which is close to the trough of the recession, the drop in job-finding probabilities is the biggest as in Figure 8(d). This is because firms are not likely to hire workers during this period. On the other hand, when the policy changes at the 5th quarter where the aggregate labor productivity starts to recover, the drop in job-finding probabilities is negligible and the employment rate does not drop at the time of the policy change.

5.2.3 Extension of duration of UI during a recession

In literature where disability insurance is not explicitly considered, the extension of the length of time people collect UI benefits decreases employment rates. This is because workers look for jobs less intensively[28] and firms have less incentives to hire workers due to higher wages resulting from higher outside options of workers.[29] However, in the presence of DI, the extended UI benefits could increase employment rate. This is because there is one more important channel in the presence of DI. The extended UI benefits induces more people to look for jobs by delaying their DI applications until UI benefits are expired.

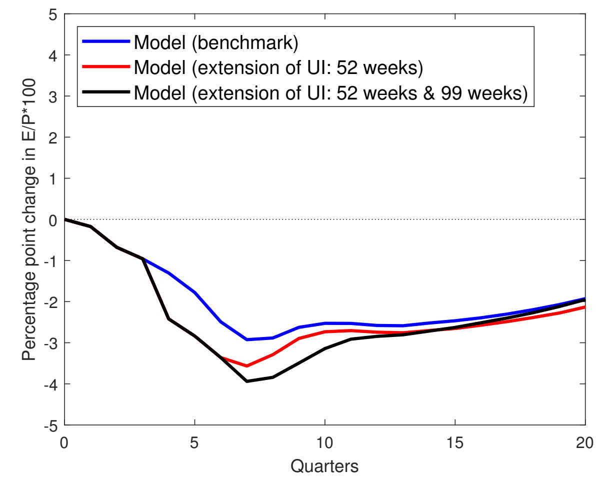
In this section, I perform an experiment in which the length of time people collect UI benefits is extended during a recession. In this experiment, we compare three different recessions:

1. Benchmark: no extension of the duration of UI benefits (26 weeks)
2. One time extension of the duration of UI benefits (26 weeks $\rightarrow$ 52 weeks at the 3rd quarter)
3. Further extension of the duration of UI benefits (26 weeks $\rightarrow$ 52 weeks at the 3rd quarter $\rightarrow$ 99 weeks at the 6th quarter)

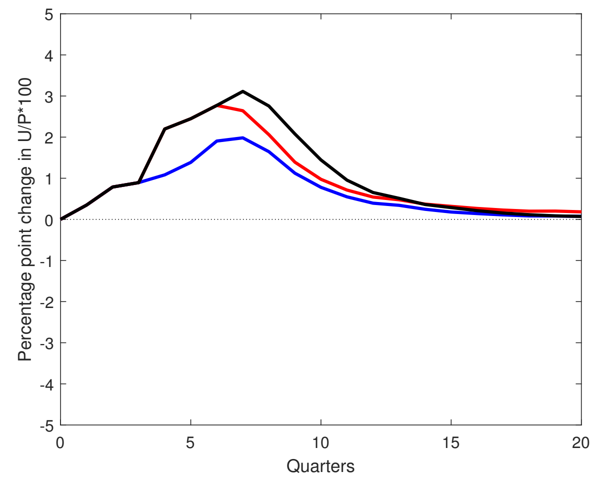
Figure 11 shows the results of the experiment. The extension of the duration of UI benefits from 26 weeks to 52 weeks during a recession leads to a deeper recession and slower recovery because it becomes more difficult for the unemployed to find jobs throughout the recession and its recovery whereas the number of people who look for jobs by delaying their DI applications does not increase much. However, if the duration is further extended from 52 weeks to 99

[28] See Nakajima (2012)
[29] See Hagedorn et at. (2019)

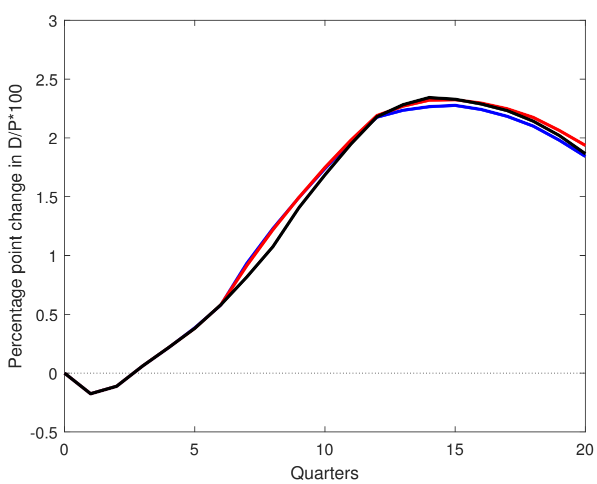
Figure 11: Results: extension of duration of UI



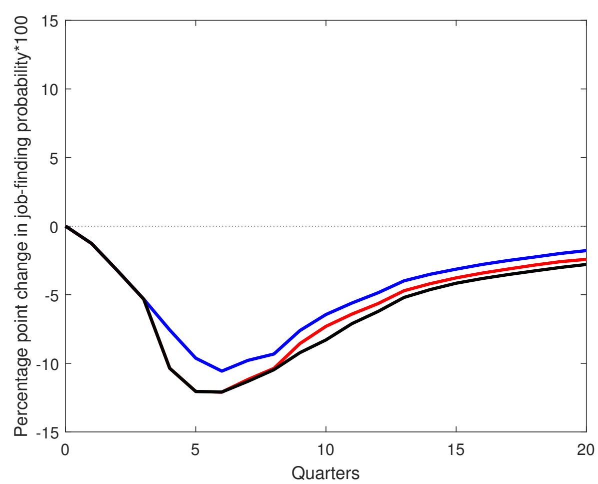
(a) Employed/Population



(b) Unemployed/Population



(c) DI recipients/Population



(d) Job-finding probabilities

Note: All series from the model are converted to quarterly series by averaging three consequent monthly series.

weeks at the 6th quarter, right after the trough of the recession, the unemployed who have work limitation are more willing to look for jobs by delaying DI applications, and this effect dominates the effect of the drop in job-finding probabilities during the recovery. Consequently, the extended UI benefits lead to a faster recovery. This result implies that the extended UI benefits during recessions can expedite recoveries in the presence of DI if the timing of extension is well designed considering the point at which the economic recovery begins.

6 Conclusion

This paper quantifies the macroeconomic effects of the DI policy change which results in a sizable number of influx of terminated DI recipients into the labor force. In particular, this paper claims that the most stringent medical re-evaluations implemented for DI recipients affect the depth of recession in 1981 and the speed of its recovery. In the US, the recovery in the employment rate of men from the 1981 recession was faster than any other recovery since 1965. The number of DI applicants and recipients during the 1981 recession and at the beginning of its recovery dropped, whereas the numbers increased in all other recessions. This decrease is attributed to the fact that the most stringent medical re-evaluations for DI recipients enforced between 1981 and 1983.

In order to quantify the effects, I build a general equilibrium business-cycle search and matching model with health, DI and unemployment insurance (UI) eligibility. The model is calibrated to match key features of the US economy for 1986-1992 by using the PSID, CPS, and public SSA data. Given that the model has aggregate labor productivity shocks and heterogeneous workers are matched randomly in the labor market, Krusell-Smith (1998) approximation is used to solve for the model outside of the steady state. Medical re-evaluations affect the number of people who search for jobs (direct effect) and job-finding probabilities for all unemployed people (general equilibrium effect). The overall effect of the policy depends on how much firms want to hire workers and the state of the economy.

To determine the effect of the policy change during the 1981 recession, I perform a simple experiment: an unexpected one-time increase in the frequency of medical re-evaluations during a recession. The experiment shows that more frequent medical re-evaluations during the 1981 recession made the recession deeper (by 1.0%-point) and the recovery faster (by 1.4%-point). Lastly, I use the model to examine the role of the extended length of time people collect UI benefits in the presence of DI during a recession. The experiment shows that in the presence of DI, the extended UI benefits during recessions can expedite recoveries if the timing of extension is well designed considering the state of the economy.

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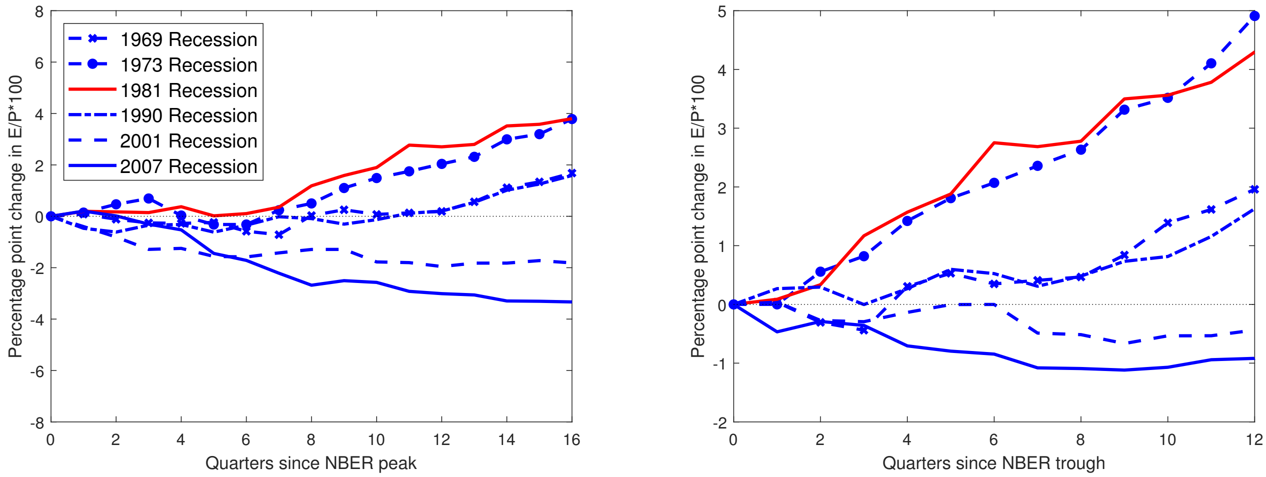
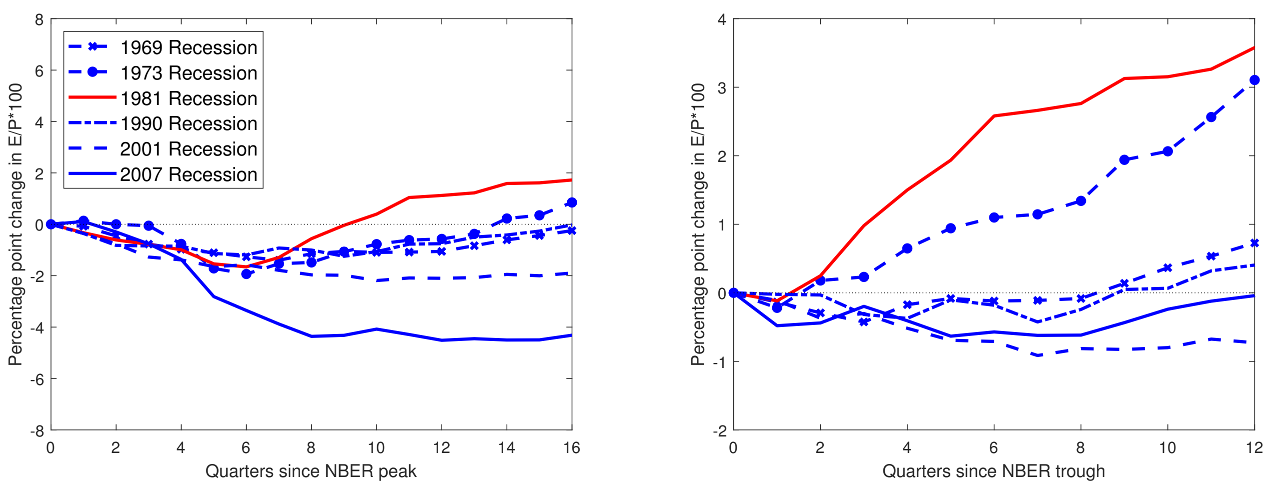
Appendix: Graphs

Figure 12: Recessions and recoveries in the employment rate of women since 1965



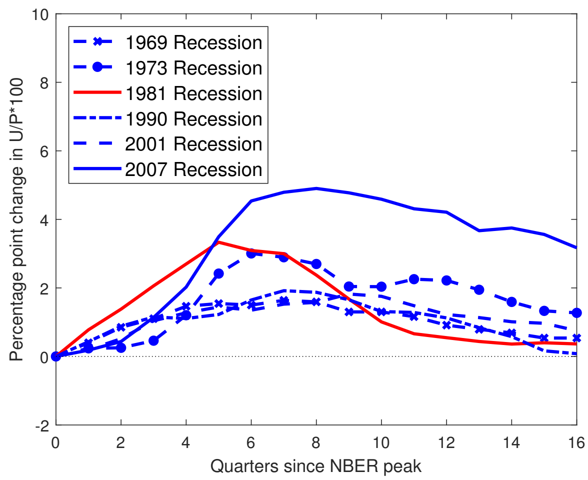
(a) Recessions and recoveries (b) Recoveries

Figure 13: Recessions and recoveries in the employment rate of men and women since 1965

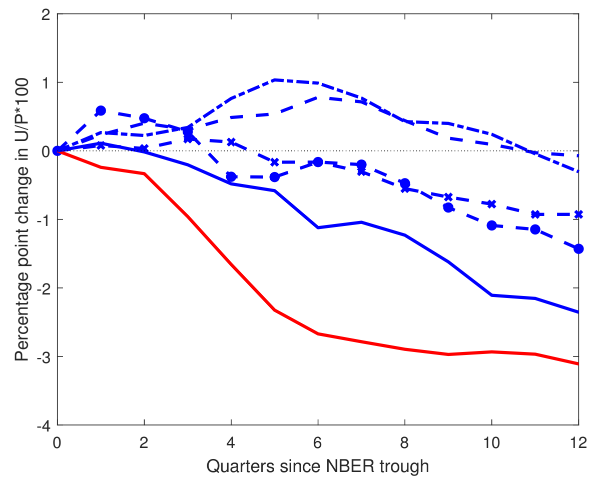


(a) Recessions and recoveries (b) Recoveries

Figure 14: Recessions and recoveries in unemployment-population ratio of men since 1965

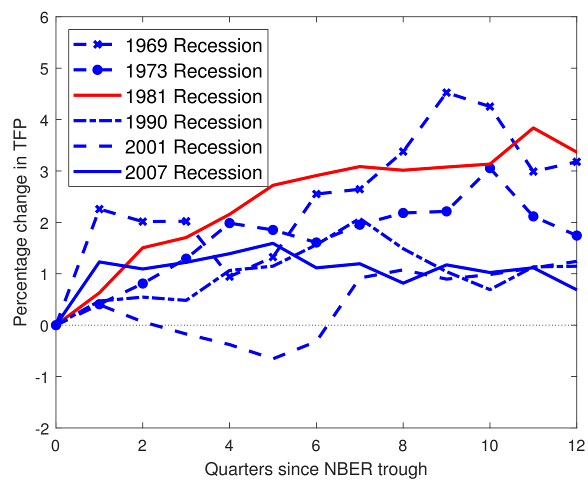


(a) Recessions and recoveries

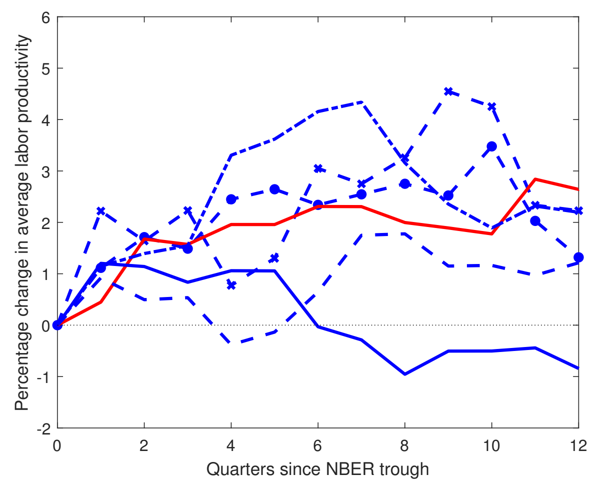


(b) Recoveries

Figure 15: Aggregate productivity during recoveries (HP-filtered)



(a) Total factor productivity (TFP)



(b) Average labor productivity

Appendix: Computation

Steady state equilibrium

In the steady state, the aggregate labor productivity is a constant. Therefore, the measure of workers ψ does not change over time. The computational algorithm for the steady state equilibrium is as follows:

1. Guess the market tightness θ
2. Given θ, Nash bargained wages and value functions for workers and firms can be solved
3. Given converged value functions, stationary measures of economy can be computed
4. Compute θ^{new} satisfies the free entry condition along with value functions for firms and measure of the economy

$$\kappa = \beta q\left(\theta\left(z,\psi\right)\right)\int E_{z,\gamma,e}\left[\left(1-s^{'}\right)J^{x}\left(\gamma^{'},e^{'};z^{'},\psi^{'}\right)\right]\frac{\psi_{s}\left(x,U,\gamma,a,m,e\right)}{\int\psi_{s}\left(x,U,\gamma,a,m,e\right)d(x,U,\gamma,a,m,e)}d(x,U,\gamma,a,m,e)$$

$$\text{where } \psi_{s}\left(x,U,\gamma,a,m,e\right)=\mathbb{I}_{\left(g_{s}^{x}\left(U,\gamma,a,m,e;z,\psi\right)=1\right)}\psi\left(x,U,\gamma,a,m,e\right)$$

5. If θ and θ^{new} are close enough, then I found the steady state. Otherwise repeat from step 2 to step 4 with a new guess for θ

$$\theta=\lambda_{\theta}\theta+\left(1-\lambda_{\theta}\right)\theta^{new}$$

Equilibrium with aggregate shocks: approximated equilibrium

Following Krusell and Smith (1998), the measure ψ is replaced with the aggregate employment E in this paper. Therefore, the aggregate state variables in this economy are $\{z,E\}$ in stead of $\{z,\psi\}$. In order to predict the market tightness θ and the future value for the aggregate employment E, I assume simple log-linear prediction functions for the market tightness $\theta\left(z,E\right)$

and the aggregate employment E[30]:

$$log\left(\theta\right) = b_{\theta,0} + b_{\theta,1}log\left(E\right) + b_{\theta,2}log\left(z\right)$$

$$log\left(E'\right) = b_{E,0} + b_{E,1}log\left(E\right) + b_{E,2}log\left(z\right)$$

Given the aggregate state variables $\{z, E\}$ and the prediction rules, I can solve the approximated equilibrium as follows:

1. Guess a set of coefficients in the prediction functions

$$b = b^{old} \equiv \left(b^{old}_{\theta,0}, b^{old}_{\theta,1}, b^{old}_{\theta,2}, b^{old}_{E,0}, b^{old}_{E,1}, b^{old}_{E,2}\right)$$

2. Given prediction rules, Nash bargained wages and value functions for workers and firms can be solved. I linearly interpolate the value functions with respect to $E^{'}$

3. Given converged value functions, I run a simulation of 10500 periods with an artificial series of $\{z_t\}_{t=1}^{10500}$ in order to generate a set of series $\{\theta_t, E_t\}_{t=1}^{10500}$. I can compute θ_t and E_t by using converged value functions in step 2, the prediction rules, and the free entry condition.

4. Once I have the set of series $\{\theta_t, E_t\}_{t=1}^{10500}$, I can update the coefficients in the prediction functions $b^{new} = \left(b^{new}_{\theta,0}, b^{new}_{\theta,1}, b^{new}_{\theta,2}, b^{new}_{E,0}, b^{new}_{E,1}, b^{new}_{E,2}\right)$ by running OLS regressions with $\{\theta_t, E_t\}_{t=501}^{10500}$. Note that I drop the first 500 observations for the regression

5. If b and b^{new} are close enough, then I found converged prediction functions. Otherwise repeat from step 2 to step 4 with a new guess for b

$$b = \lambda_b b^{old} + \left(1 - \lambda_b\right) b^{new}$$

6. I use R^2 for the measure for accuracies of the prediction functions. The following are the

[30] This is a simpler version of prediction functions in Bils et al. (2011)

converged prediction functions and their accuracies for the baseline model:

$$log\left(\theta\right) = 0.5340 + 0.1033\,log\left(E\right) + 0.8329\,log\left(z\right),\ \ R^2 = 0.9524$$

$$log\left(E'\right) = -0.0001 + 0.9993\,log\left(E\right) + 0.0015log\left(z\right),\ \ R^2 = 0.9987$$