

State Dependence in Labor Market Fluctuations: Evidence, Theory and Policy Implications*

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April 2017

Abstract

This paper documents a novel fact: the volatility of the unemployment rate and the job separation rate is larger in periods with low aggregate productivity. A Diamond-Mortensen-Pissarides model with endogenous job separation and on-the-job search replicates these empirical regularities well. Endogenous job separation embeds powerful state dependence: fluctuations in the job separation rate are larger in periods of low aggregate productivity and in response to contractionary shocks. State dependence implies that the effect of labor market reforms is different across phases of the business cycle. A permanent removal of layoff taxes is welfare-enhancing in the long run, but it involves distinct short-run costs depending on the initial state of the economy. The welfare gain of a tax removal implemented in a low-productivity state is 3.5 percent larger than the same reform in the state with high aggregate productivity.

JEL Classification: E24, E32, J64.

Keywords: Search and Matching Models, State Dependence in Business Cycles.

*We would like to thank Paul Beaudry, Anton Braun, Alex Clymo, Jesus Fernandez-Villaverde, Jean Flemming, Francesco Furlanetto, Masashige Hamano, Gabriele Galati, Harald Uhlig, Federico Mandelmann, Peter Ireland, Paulo Santos Monteiro, John Muellbauer, Juan Rubio-Ramirez, Morten Ravn, Ricardo Reis, Michal Rubaszek, Frank Schorfheide, Tao Zha, Yang Yu and seminar participants at the Asian Development Bank Institute, De Nederlandsche Bank, Federal Reserve Bank of Atlanta, Bank of Japan, Narodowy Bank Polski, Norges Bank, University of Oxford, University of Sophia, University of Tokyo, University of York, the annual conference of the Royal Economic Society (Sussex) and the Econometric Society Meetings of the European Economic Association (Geneva) for extremely valuable comments. The present project was partially supported by the John Fell Fund. Please address correspondence to Carlo Pizzinelli or Francesco Zanetti, University of Oxford, Department of Economics, Manor Road, Oxford, OX1 3UQ, UK; Emails: Carlo.Pizzinelli@economics.ox.ac.uk or Francesco.Zanetti@economics.ox.ac.uk.

1 Introduction

Numerous studies show that fluctuations in macroeconomic variables are different across phases of the business cycle.¹ This paper builds on this strand of research and identifies systematic changes in the cyclical properties of labor market variables that are tightly linked to the state of aggregate productivity: movements in the unemployment rate and the job separation rate are considerably larger in periods of low productivity.

To explain this novel finding and assess the policy implications, we develop a Diamond-Mortensen-Pissarides (DMP) search model with endogenous job separation and on-the-job search (OJS) that entails state dependence in labor market fluctuations across different states of aggregate productivity (i.e., low versus high) and in reaction to contractionary and expansionary shocks. In a state with low aggregate productivity, the firm retains profits by setting a high threshold of individual productivity that yields match efficiency, dismissing jobs with individual productivity below the threshold. The high threshold is associated with a high density of jobs. Therefore an exogenous movement in aggregate productivity that changes the threshold generates large shifts in the job separation rate and the unemployment rate in periods of low productivity. Conversely, in a state with high aggregate productivity, the firm sets a low threshold for efficient matches that is associated with a low density of jobs and therefore an equivalent change in productivity produces limited movements in the job separation and unemployment rates.

The model shows that labor market responses are different across contractionary and expansionary shocks. In the aftermath of a contractionary productivity shock, the firm raises the threshold of individual productivity for efficient matches and terminates jobs with productivity lower than the threshold, instantly increasing the job separation rate. Conversely, in response to an expansionary productivity shock, the firm decreases the threshold of individual productivity for efficient matches and terminates a limited number of jobs since the productivity of most workers is higher than the threshold. This mechanism makes the job separation rate and the unemployment rate more responsive to contractionary productivity shocks than to expansionary ones.

To illustrate the importance of state dependence for labor market reforms, we enrich the baseline model with layoff taxes levied on the firm for the termination of existing jobs but averted on matches that fail to result in job relations.² The layoff tax increases

¹Seminal studies are those by Neftci (1984), Sichel (1989) and Beaudry and Koop (1993), followed by more recent studies by McKay and Reis (2008), Bachmann *et al.* (2013) and Mumtaz and Surico (2015).

²To the best of our knowledge, this is the first study to introduce firing taxes in a general equilibrium

the surplus of job relations that continue into the next period since they forego the tax payment but it reduces the surplus of new matches in the prospect of paying the layoff tax if the job relation terminates in the future. The tax commands a high threshold of individual productivity to make new matches profitable and therefore discourages OJS. The pool of job seekers diminishes, and the firm's recruiting costs for establishing a profitable match rise, leading to a decrease in hiring. Overall, the layoff tax considerably reduces the job finding rate and increases the pool of workers subject to job separation by discouraging OJS. These complementary forces generate a rise in the unemployment rate.³

We use the model with layoff taxes to assess whether an unexpected and permanent removal of the tax generates distinct transitional dynamics and welfare effects in states with low and high aggregate productivity. In the long run, the elimination of the tax generates a fall in the unemployment rate and a rise in output that is welfare-enhancing regardless of the initial states of aggregate productivity. In the short run, however, the reform generates sharp differences in the transitional dynamics of labor market variables across initial states. The unemployment rate gradually declines in the state with high aggregate productivity whereas it suddenly contracts in the state with low aggregate productivity. These temporary differences disappear after four quarters, but they produce significant welfare differences. The tax removal raises the surplus of establishing a job relation and induces firms to post vacancies and workers to search on the job to extract the enhanced benefits of forming an employment relation. Search efforts are stronger in the state with high aggregate productivity since the joint surplus of forming a job is larger while aggregate productivity is high. The considerable rise in search efforts in the state with high aggregate productivity generates large temporary welfare losses caused by deadweight search costs of matching frictions. The total discounted welfare gain of a tax removal enacted in the state with low aggregate productivity is 3.5 percent larger than the same reform in the state with high aggregate productivity.

Our analysis relates to empirical and theoretical studies on the state dependence of labor market fluctuations over the business cycle. On the empirical side, the studies by Neftci (1984), Altissimo and Violante (2001), Panagiotidis and Pelloni (2007), Barattieri

model with endogenous job separation and OJS. Layoff taxes are modeled as a deadweight loss, similar to Pissarides (2000). We focus on layoff taxes since Cacciatore and Fiori (2016) show that they are effective policies in reducing inefficiencies of unemployment fluctuations. In addition, an array of studies show that they are powerful in affecting labor market outcomes (see, for example, Campolmi and Faia (2011), Zanetti (2011) and references therein).

³As we discuss in section 6.2, there is no established consensus on the effect of layoff taxes on the level of the unemployment rate. We contribute to this realm of research by showing that OJS plays a critical role for the effect of layoff taxes on unemployment.

et al. (2014), Benigno *et al.* (2015) and Caggiano *et al.* (2014) show that unemployment and wages move differently across phases of the business cycles. Compared to these studies, we establish important state dependence in labor market fluctuations linked to the state of aggregate productivity, and we extend the analysis to job transition rates. On the theoretical side, the analysis is related to studies that develop structural models to investigate state dependence and nonlinearities of macroeconomic variables over the business cycle. Kim and Ruge-Murcia (2009), Aruoba *et al.* (2013) and Gortz and Tsoukalas (2013) show that standard models replicate important nonlinearities in the data, if enriched with asymmetric adjustment costs. Abbritti and Fahr (2013), Benigno and Ricci (2011) and Benigno *et al.* (2015) show that asymmetric wage rigidities change the propagation of exogenous disturbances and have important welfare effects for stabilization policies. Petrosky-Nadeau and Zhang (2013) and Ferraro (2016) develop search models that replicate asymmetries in labor market data over the business cycle. Different from the aforementioned studies, our analysis considers state dependence rather than unconditional asymmetries of the labor market over the cycle and links it with labor market reforms.

Finally, this work relates to the growing literature that explores the state-dependent effect of labor market policies on aggregate fluctuations. In the context of search and matching models, Cacciatore and Fiori (2016) and Cacciatore *et al.* (2015) show that the effect of labor market deregulation changes nonlinearly with the level of unemployment and responses of labor market variables are different across phases of the business cycles. Michailat (2014) develops a search model of the labor market that partitions jobs into public and private sectors and shows that the effect of government spending is nonlinear and less effective in periods of economic expansions since public employment crowds out private employment. Cacciatore *et al.* (2016) develop a model with labor market frictions and endogenous producer entry and show that the effect of changes in layoff taxes are significantly different across periods of economic expansions and contractions. The aforementioned studies show that labor market reforms involve important nonlinear effects on labor market fluctuations. Our analysis complements these findings by focusing on the different transitional dynamics and welfare effects of the removal of layoff taxes implemented at distinct states of aggregate productivity.

The remainder of the paper is structured as follows. Section 2 presents the empirical findings. Section 3 lays out the model. Section 4 discusses the mechanisms that generate state dependence in labor market fluctuations across distinct states of aggregate productivity and in response to contractionary and expansionary shocks. Section 5 presents model simulations and quantitative results. Section 6 assesses the implementations of

labor market reforms. Section 7 concludes.

2 Empirical evidence

This section isolates systematic differences in the fluctuations of labor market variables linked to the state of productivity and it shows skewness in labor market data.

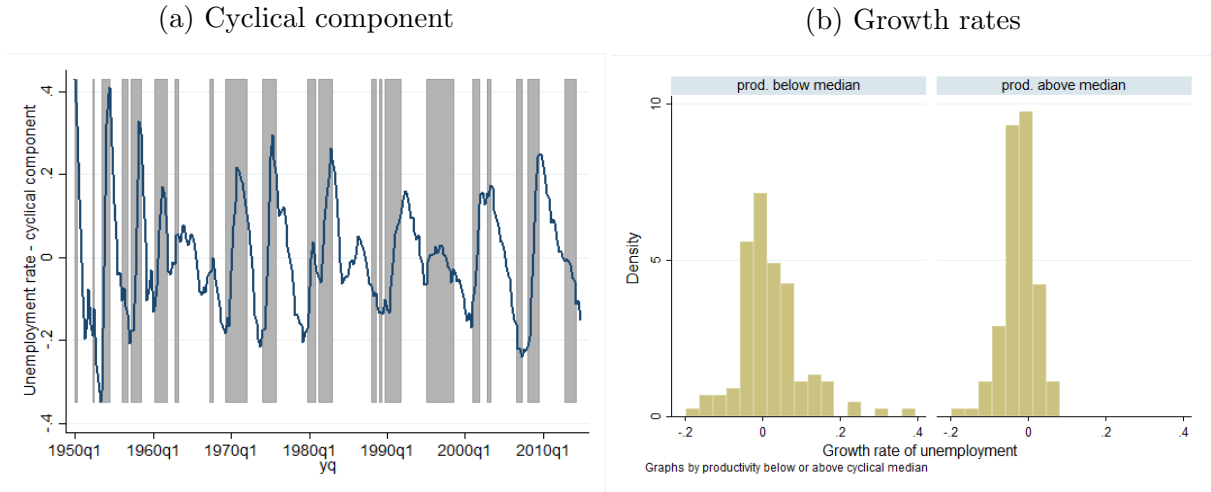
We use quarterly series for the (un)employment rate, the job finding rate, the job separation rate, output and labor productivity over the period 1950:I-2014:IV. To extract the cyclical component of variables, we use an HP filter with a smoothing parameter equal to 1,600.⁴ Panel (a) in Figure 1 plots cyclical movements in the unemployment rate (solid line) against periods of labor productivity below the median value (shaded area). Especially in the early part of the sample, the largest movements in the unemployment rate occur during period of below-trend productivity. This dynamic is less pronounced since the early 1990's, where longer periods of slow decreases in unemployment have been named "jobless recoveries." Panel (b) in the figure shows histograms of the unemployment rate in periods with labor productivity below (left entry) and above (right entry) the historical median. A comparison across the two histograms reveals that changes in the unemployment rate are significantly larger in periods of aggregate productivity below the median value. This first pass to the data outlines systematic differences in the variability of the unemployment rate that are linked to the state of productivity. In the subsequent analysis, we use statistical methods to isolate significant changes in the cyclical properties of a wider range of labor market variables across distinct states of productivity.

Table 1 shows the standard deviation of the HP-filtered series (columns (1)-(3)) and growth rates of the series (columns (4)-(6)) over the sample period. The table reports the standard deviation of the variables when labor productivity is below (columns (1) and (4)) and above (columns (2) and (5)) the median value of its cyclical component, and the ratio of the standard deviations of each variables in periods when productivity is below and above the median value (columns (3) and (6)). The entries consistently show that the standard deviation of most of the variables in levels is 20 to 30 percent larger in periods of productivity below its median value, and even twice larger in growth rate. Interestingly, the job finding rate exhibits limited differences across states of productivity.⁵

⁴Appendix A provides data sources. Results are robust across using a HP filter with smoothing parameter equal to 10^5 , consistent with Shimer (2005), applying the first difference operator to each original series, using alternative filtering methods, selecting different subperiods and if we use the measure of productivity adjusted for factor utilization by Fernald (2012). Robustness checks are reported in Appendix J.

⁵Appendix J shows that results continue to hold if we use a smoothing parameter for the HP filter equal to 10^5 , the productivity series by Fernald (2012), different sample periods and the specification of

Figure 1: The unemployment rate and states of productivity



Notes: Panel (a) shows the cyclical movements in the unemployment rate (solid line) together with periods of labor productivity below the median value (shaded area). Panel (b) shows histograms of the unemployment rate when productivity is below (left entry) and above (right entry) the median value.

Table 1: Standard deviation for different states of productivity

	HP-filtered			First difference		
	$\sigma_{p < Median}$ (1)	$\sigma_{p > Median}$ (2)	$\frac{\sigma_{p < Median}}{\sigma_{p > Median}}$ (3)	$\sigma_{p < Median}$ (4)	$\sigma_{p > Median}$ (5)	$\frac{\sigma_{p < Median}}{\sigma_{p > Median}}$ (6)
Unemployment	0.146	0.120	1.23	0.0829	0.0401	2.06
Job Finding Rate	0.037	0.034	1.07	0.0240	0.0192	1.25
Job Separation Rate	0.0021	0.0013	1.57	0.019	0.00157	1.25
Employment	0.009	0.007	1.32	0.0051	0.0023	2.15
Output	0.022	0.016	1.34	0.0153	0.0090	1.71
Productivity	0.012	0.009	1.25	0.0099	0.0074	1.34

Notes: Appendix A provides data sources. The data is quarterly over the period 1950:I-2014:IV. The series of the (un)employment rate, output and productivity are in logs. Series are HP-filtered with a smoothing parameter equal to 1,600. Growth rates are log differences of quarterly averages.

$\sigma_{p < (>) Median}$ represents the standard deviation of the variable for the productivity state below (above) the median.

These findings further point to large and systematic differences in the variability of labor market variables across states of aggregate productivity. To ensure results are unbiased by the larger volatility of labor productivity itself in periods with low aggregate productivity, we use regression analysis that estimates the correlation across labor

the variables in growth rates.

market variables and productivity controlling for the level of productivity. Table 2 regresses the log (un)employment rate, the job finding rate and the separation rate on log productivity ($\log p_t$), a dummy variable equal to one when productivity is above its historical median value ($\text{High-}p_t$) and an interaction term between the two variables ($\text{High-}p_t * \log p_t$) that captures the differential effect of productivity in periods with high economic activity. Since the response of labor market variables to changes in aggregate conditions may be delayed, we include the explanatory variables with a lag, and to capture persistence, we also include the dependent variable with a lag.⁶ Column (1) shows that the unemployment rate is negatively correlated to changes in current-period productivity. The interaction term is positive, implying that in times of productivity above the median value the negative correlation between productivity and the unemployment rate is reduced. Column (2) shows that the job finding rate is positively correlated with current-period productivity. The coefficient in the interaction term is negative, therefore indicating that the positive correlation is smaller in states with high productivity. The weak statistical significance is consistent with the fact that the ratio of volatilities from Table 1 is only marginally greater than one. Column (3) shows that the separation rate responds negatively to current-period productivity. The coefficient of the interaction term is large and positive, implying a much reduced negative correlation between these variables in states with high productivity. An equivalent result holds for the employment rate in column (4). Overall, the results from regression analysis corroborate the evidence from the preceding analysis, pointing to larger labor market fluctuations in the state with productivity below the median value. Table 3 performs the same exercise using the growth rate of the variables and shows that results continue to point to a larger response of labor market variables in period of productivity growth below the median value.⁷

Overall, statistical evidence consistently points to systematic differences in the cyclical movements of important labor market variables that are linked to the state of productivity. A recent study by Ferraro (2016) establishes that the employment rate is negatively skewed in levels and growth rate and that the job finding and job separation rates are jointly responsible for the asymmetric distribution of the employment rate. To ensure our analysis appraises this dimension in the data, we test for skewness in the unemployment rate, the job separation rate and the job finding rate. Table 4 shows the excess skewness test by Bai and Ng (2005) and reports the skewness coefficient for the distribution of each variable together with the associated one-tailed p -value (in parenthesis).

⁶The results continue to hold if we have no lags or if we include additional (two and three) lags of the explanatory variables.

⁷Appendix K shows that results continue to hold if we use a smoothing parameter in the HP filter equal to 10^5 , the productivity series by Fernald (2012) and different sample periods.

Table 2: Regression analysis, specification in levels

Variables	$\log U_t$ (1)	JFR_t (2)	JSR_t (3)	$\log E_t$ (4)
$\log p_t$	-4.834*** (0.582)	0.842*** (0.226)	-0.120*** (0.0166)	0.294*** (0.032)
High- p_t	0.0155* (0.009)	-0.001 (0.003)	0.000 (0.000)	-0.001** (0.000)
$\log p_t$ *High- p_t	2.734*** (0.890)	-0.679* (0.353)	0.104*** (0.026)	-0.172*** (0.050)
$\log p_{t-1}$	-0.171 (0.630)	0.374 (0.244)	0.025 (0.018)	0.070* (0.036)
High- p_{t-1}	-0.003 (0.009)	0.000 (0.003)	0.000 (0.000)	-0.000 (0.000)
$\log p_{t-1}$ *High- p_{t-1}	0.977 (0.906)	-0.182 (0.357)	-0.029 (0.027)	-0.111** (0.051)
Lagged dependent	0.884*** (0.024)	0.775*** (0.034)	0.345*** (0.0593)	0.878*** (0.022)
Constant	-0.026*** (0.007)	0.005* (0.003)	-0.000** (0.000)	0.002*** (0.000)
Observations	259	259	259	259
R-squared	0.890	0.762	0.479	0.911

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Notes: Columns (1)-(4) report the log unemployment rate, the job-finding rate, the separation rate, and the log employment rate, respectively. All time series are HP-filtered with a smoothing 1,600 parameter. The explanatory variables are the log productivity, a dummy variable equal to one when productivity at time t is larger than the historical median, and an interaction term between the log productivity and the dummy variable.

The entries show statistically significant positive (negative) skewness in levels and growth rates of the unemployment (employment) rate. The job finding rate is not significantly skewed in levels and growth rates. Meanwhile, the job separation rate shows significant positive skewness both in levels and growth rates.⁸ Overall, these findings suggest that fluctuations in the unemployment (employment) rate and the job separation rate display statistically significant skewness over the business cycle.⁹

⁸An appendix that provides extensive robustness checks on the skewness of the series is available on request to the authors.

⁹Appendix L shows that results continue to hold if we use a smoothing parameter in the HP filter equal to 10^5 , the productivity series by Fernald (2012), different sample periods and the specification of the variables in growth rates.

Table 3: Regression analysis, specification in growth rates

Variables	ΔU_t (1)	ΔJFR_t (2)	ΔJSR_t (3)	ΔE_t (4)
Δp_t	-3.500*** (0.507)	0.777*** (0.184)	-0.0854*** (0.015)	0.193*** (0.030)
High- p_{t-1}	-0.042*** (0.011)	0.011*** (0.0038)	-0.001** (0.000)	0.002*** (0.001)
$\Delta p_t * \text{High-}p_{t-1}$	1.694** (0.826)	-0.596** (0.299)	0.067*** (0.025)	-0.096* (0.049)
Δp_{t-1}	-2.529*** (0.555)	0.762*** (0.201)	0.014 (0.017)	0.194*** (0.033)
High- p_{t-2}	-0.035*** (0.010)	0.007* (0.004)	0.000 (0.000)	0.00288*** (0.001)
$\Delta p_{t-1} * \text{High-}p_{t-2}$	1.555* (0.830)	-0.041 (0.301)	-0.027 (0.025)	-0.142*** (0.049)
Constant	0.064*** (0.007)	-0.016*** (0.002)	0.000* (0.000)	-0.004*** (0.000)
Observations	258	258	258	258
R-squared	0.360	0.231	0.121	0.383

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Notes: Variables are expressed in growth rates. Columns (1)-(4) report the growth rates of the unemployment rate, the job-finding rate, the separation rate, and the employment rate, respectively. The explanatory variables are the growth rate of productivity, a dummy variable equal to one when productivity at time t is larger than the historical median, and an interaction term between the growth rate of productivity and the dummy variable.

Table 4: Skewness in the data

	HP-filtered	Growth rate
Unemployment	0.403 (0.060)	1.385 (0.045)
Job Finding Rate	-0.292 (0.103)	-0.385 (0.160)
Separation Rate	0.772 (0.014)	0.478 (0.042)
Employment	-0.666 (0.005)	-1.214 (0.010)
Output	-0.509 (0.023)	-0.098 (0.356)
Productivity	-0.363 (0.052)	0.070 (0.270)

Notes: The skewness test is based on Bai and Ng (2005). P -values are reported in parenthesis.

3 The model

This section lays out a DMP search and matching model enriched with endogenous job separation and OJS. The model is based on den Haan *et al.* (2000), Fujita and Ramey (2012), Krause and Lubik (2007) and Thomas and Zanetti (2009). However, it differs from these studies in allowing for the separation of newly-established jobs and introducing layoff taxes on the termination of existing jobs.¹⁰

Economic environment and timing. A continuum of households of mass 1 and a continuum of firms operate in a discrete time environment. Households supply labor to firms inelastically. Matching frictions in the labor market prevent full employment. Firms pay a fixed cost for each vacancy posted to recruit new workers. However, neither are all vacancies filled nor are all job-seekers hired in a given period. Employed workers produce a single consumption good, whose price is normalized to one, and they may search for a new job while employed. In every period t , production by a single worker depends on aggregate labor productivity, a_t , and individual, idiosyncratic productivity, x . For each a_t , there is a reservation level of individual productivity $x^r(a_t)$, below which jobs are not mutually efficient and are dismissed. Similarly, there is a level of individual productivity $x^s(a_t)$, below which employed workers find it efficient to pay a fixed cost to search for other jobs.¹¹ Employment results from past employment, net of job separation and newly created jobs.

Within each period t , the timing of events is as follows. At the start of period t , firms post vacancies that are matched with job seekers by the end of the period. Employed workers produce and may search for a new job within the period. At the end of the period, a fraction of employed workers is exogenously separated, and another fraction of employed workers obtains a new draw of individual productivity. At the beginning of the next period $t + 1$, aggregate productivity a_{t+1} and the individual productivity x of each worker are observed. Each firm converts profitable matches into jobs, and each worker that searches on the job decides whether to move to a new firm or remain in the current job.

¹⁰The baseline model described in this section abstracts from layoff taxes, which are introduced in the extended version of the model in Section 6.

¹¹Below, we use the following notation: when x has a time subscript, it refers to an aggregate state (e.g. x_t^r is the individual productivity threshold that applies to all firms given an aggregate productivity level a_t). Without a subscript, it refers to any individual productivity level for a match independent of aggregate states.

The matching function. A matching function encapsulates search frictions in the labor market. In each period t , the constant-returns-to-scale matching function establishes the number of matches between job seekers and vacancies, $m_t = m(u_t + \psi_t, v_t) < \min[u_t + \psi_t, v_t]$, where u_t is unemployment, ψ_t is the mass of OJS workers and v_t are vacancies. The sum of employed OJS workers and unemployed workers forms the number of effective job searchers. The probability for a job seeker to fill a vacancy and for a vacancy to be filled can be expressed in terms of the “labor market tightness,” defined as the ratio of vacancies to job seekers, $\theta_t = v_t/(u_t + \psi_t)$. The probability of a job seeker to find a suitable vacancy is $p(\theta_t) = m(u_t + \psi_t, v_t)/(u_t + \psi_t) = m[1, v_t/(u_t + \psi_t)]$ and the probability for the firm to find a suitable worker is $q(\theta_t) = m[(u_t + \psi_t), v_t]/v_t = m[(u_t + \psi_t)/v_t, 1]$.¹²

Production and matched workers. Each firm manufactures a unique final good by hiring labor. Each hired worker produces $a_t x$ units of output. Individual productivity x follows a first-order Markov process with variance σ_x^2 . Aggregate productivity a_t follows the auto regressive process:

$$\ln a_{t+1} = \rho \ln a_t + \epsilon_{t+1}, \quad (1)$$

where $\epsilon \sim N(0, \sigma^2)$ and $\|\rho\| < 1$. During each period $t + 1$, an existing worker maintains the previous individual productivity level with probability $(1 - \lambda)$, and with probability λ , the worker receives a new productivity drawn from the constant distribution $F(x)$ over the domain $[x_L, x_H]$. Job seekers matched in period t also receive a productivity value from the same distribution in the beginning of period $t + 1$.

Job separation and job creation. During each period t , total job separations comprise exogenous and endogenous job terminations. Existing workers are separated from their jobs with the exogenous probability of $s < 1$. Given aggregate productivity a_t , the firm establishes a threshold of individual productivity $x^r(a_t)$, below which existing matches are mutually inefficient. All workers whose individual productivity satisfies $x \leq x^r(a_t)$ are dismissed whereas if $x > x^r(a_t)$, the job relation continues in the next period.

On-the-job search. A worker may search for a new job at the cost k^s . An employed job searcher is matched to a firm from the same pool as the unemployed job seekers and therefore is subject to the same matching frictions. Once matched, the worker

¹²As we discuss below, due to individual productivity shocks, $p(\theta_t)$ and $q(\theta_t)$ cannot be interpreted as the job finding and job filling probabilities, respectively. We therefore refer to them as the “contact” probabilities for workers and firms, respectively. Also note that labor market tightness is different from the empirically observable vacancy-unemployment ratio.

receives an idiosyncratic x from the distribution $F(x)$ as any other newly-matched job seeker. If the draw of individual productivity is below the reservation threshold, the match is discontinued and the employed job searcher stays in the original job. Also, as any existing worker, the job searcher who remains with her current firm draws a new individual productivity with probability λ and faces exogenous job separation. Each firm applies the same separation threshold to employed and unemployed job seekers.¹³

Recursive formulation. Four value functions solve the model: the value of unemployment (U), the value of a vacancy (V), the *joint* value of a match (M) and the *joint* surplus of a match (S). The joint surplus of a match is split in constant proportions, assigning the fraction ϕ of the joint match surplus to the worker and the fraction $1 - \phi$ to the firm. The value of unemployment is:

$$U(a_t) = b + \beta \mathbb{E}_t \left[U(a_{t+1}) + p(\theta_t) \phi \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right]. \quad (2)$$

Equation (2) shows that the value of unemployment is equal to the opportunity cost of working (i.e., the flow value of unemployment b) and the expected benefits that finding a job brings in the next period. In period $t+1$, the perspective worker encounters a suitable vacancy with probability $p(\theta_t)$, and if the match is mutually profitable, the worker gains a fraction (ϕ) of the total surplus. Otherwise the job seeker remains unemployed, gaining the continuation value $U(a_{t+1})$.

The value of an open vacancy is:

$$V(a_t) = -k + \beta \mathbb{E}_t \left[V(a_{t+1}) + q(\theta_t)(1 - \phi) \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right]. \quad (3)$$

Equation (3) shows that the present value of an open vacancy is equal to the fixed cost of posting the vacancy (k) and the expected benefits that the vacancy brings in the next period. In period $t + 1$, the firm finds a perspective worker with probability $q(\theta_t)$, and if the match is profitable, the firm gains a fraction $(1 - \phi)$ of the total surplus. Otherwise, the vacancy remains open, gaining the firm a continuation value, $V(a_{t+1})$. In equilibrium, the free-entry condition leads firms to post vacancies until their expected value is equal to zero in each period (i.e. $V(a_t) = 0$, for all t). This equilibrium condition

¹³This simplifying assumption abstracts from the fact that the actual outside option for employed job seekers is their current employment contract rather than unemployment. This simplification avoids the issue of heterogeneity in wage bargaining and hence the fact that new wages depend on the value of x for the current contract and the value of x from the previous employer. These dynamics substantially complicate the aggregation for the solution of the model. We leave these interesting extensions open to future research. In this direction, see the work of Gertler *et al.* (2016).

applied on equation (3) yields the job-creation condition:

$$\frac{k}{q(\theta_t)} = (1 - \phi)\beta\mathbb{E}_t \left[\int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right]. \quad (4)$$

Equation (4) shows that the expected cost of a match (left-hand side of the equation) is equal to the expected benefit that the match brings into the firm if the job is established (right-hand side of the equation). With this formulation, the problem of the firm can be recast in terms of choosing a given market tightness $\theta(a_t)$ for a level of aggregate productivity.

For each given vector of (a_t, x) , an employment relationship is established if the match is mutually efficient, and therefore the joint value of establishing a job relation is greater than the value of the outside options (i.e., the individual values from separation). Thus, the joint value of a firm-worker match is:

$$M(a_t, x) = \max[M^{n,c}(a_t, x), M^{s,c}(a_t, x), U(a_t) + V(a_t)], \quad (5)$$

where $M^{n,c}(a_t, x)$ is the joint value of a continued match without OJS, $M^{s,c}(a_t, x)$ is the joint value of the continued match with OJS, and $U(a_t) + V(a_t)$ is the joint value of the outside option.

The joint value of a continued match without OJS is:

$$M^{n,c}(a_t, x) = a_t x + \beta\mathbb{E}_t \left\{ U(a_{t+1}) + V(a_{t+1}) + (1 - s) \left[(1 - \lambda)S(a_t, x) + \lambda \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right] \right\}. \quad (6)$$

Equation (6) shows that the value of a continued match is equal to production plus the expected continuation value of the work relationship. Meanwhile the value of a continued match while searching on the job is

$$M^{s,c}(a_t, x) = a_t x - k^s + \beta\mathbb{E}_t \left\{ U(a_{t+1}) + V(a_{t+1}) + \left[1 - p(\theta) \overline{F(x_{t+1}^r)} \right] (1 - s) \left[(1 - \lambda)S(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right] + p(\theta)\phi \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right\}. \quad (7)$$

where $\overline{F(x_{t+1}^r)} = (1 - F[x^r(a_{t+1})])$ is the probability that the employed searcher is matched with a vacancy but the match is not formed because its value is below the

firm's reservation cutoff. The last term uses the fact that $\int_{x^r(a_{t+1})}^{x_H} S(a_{t+1}, x') dF(x') = \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x')$. This term represents the expected surplus that may accrue to the worker if she is matched with another firm and the match is continued. This event materializes with probability $p(\theta_t) \overline{F(x_{t+1}^r)}$, and encompasses all the values of x above the reservation threshold x_{t+1}^r .

The joint surplus of a match equals the value of a match, M , net of the outside option for the worker, U , and the firm, V (i.e. $S=M - U - V$). Thus, the value function for the joint surplus of a continuing match is:

$$S(a_t, x) = \max[S^{n,c}(a_t, x), S^{s,c}(a_t, x), 0], \quad (8)$$

where $S^{n,c}(a, x)$ is surplus of the match when the job relation continues without OJS and $S^{s,c}(a, x)$ is the surplus of a continued match with OJS. The surpluses are defined as follows:

$$S^{n,c}(a_t, x) = a_t x - b + \beta \mathbb{E}_t \left\{ (1-s) \left[(1-\lambda) S(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right] - p(\theta_t) \phi \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right\}, \quad (9)$$

$$S^{s,c}(a_t, x) = a_t x - k^s - b + \beta \mathbb{E}_t \left\{ \left[1 - p(\theta_t) \overline{F(x_{t+1}^r)} \right] (1-s) \left[(1-\lambda) S(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right] \right\}. \quad (10)$$

A worker searches while on the job if $S^{s,c}(a_t, x) \geq S^{n,c}(a_t, x)$. The presence of OJS introduces a threshold $x^S(a_t)$, below which it is efficient to search on the job. For values of the threshold $x^r(a_t) < x^S(a_t) < x_H$, it is efficient to incur in the search costs for all $x \in (x^r(a_t), x^S(a_t)]$. Substituting equations (9) and (10) into the condition $S^{s,c}(a_t, x) \geq S^{n,c}(a_t, x)$ yields

$$k^s \leq \beta \mathbb{E}_t \left\{ p(\theta_t) \overline{F(x_{t+1}^r)} (1-s) \left[(1-\lambda) S(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right] - p(\theta_t) \phi \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right\}. \quad (11)$$

Equation (11) determines the efficient threshold under which workers engage in OJS. Intuitively, the cost of searching has to be smaller than the increase in the continuation value coming from possibly finding a new match.

Finally, for a given aggregate state a_t , the individual productivity threshold for exogenous separations is the value of x which makes the joint surplus of continuing a match equal to zero, such that¹⁴

$$S^{s,c}(a_t, x^r(a_t)) = 0. \quad (12)$$

Labor flows. Labor flows depend on the distribution of x across employed matches. The distribution of individual productivity among employed workers is history dependent: $G_t(x) = Pr(X < x | a^t)$, where a^t represents the history of aggregate productivity shocks $\{a_0, a_1, \dots, a_t\}$ realized up to time t . The conditional distribution is determined by the measure of employed workers over individual productivity, $e_t(x)$, which follows a law of motion determined by the flows between unemployment and employment and within employment. For those workers whose individual productivity is in the OJS interval $(x_t^r, x_t^s]$:

$$\begin{aligned} e_{t+1}(x) = & p(\theta_t)[1 - e_t(x_H)][F(x) - F(x_{t+1}^r)] + p(\theta_t)[F(x) - F(x_{t+1}^r)]e_t(x_t^s) \\ & + (1 - s) \left\{ \lambda[F(x) - F(x_{t+1}^r)] \left[e_t(x_H) - p(\theta_t) \overline{F(x_{t+1}^r)} e_t(x_t^s) \right] \right. \\ & \left. + (1 - \lambda) \left[e_t(x) - e_t(x_{t+1}^r) \right] \left[1 - p(\theta_t) \overline{F(x_{t+1}^r)} \right] \right\}. \quad (13) \end{aligned}$$

For the non-searching workers, with $x > x_t^s$:

$$\begin{aligned} e_{t+1}(x) = & p(\theta_t)[1 - e_t(x_H)][F(x) - F(x_{t+1}^r)] + p(\theta_t)[F(x) - F(x_{t+1}^r)]e_t(x_t^s) \\ & + (1 - s) \left\{ \lambda[F(x) - F(x_{t+1}^r)] \left[e_t(x_H) - p(\theta_t) \overline{F(x_{t+1}^r)} e_t(x_t^s) \right] \right. \\ & \left. + (1 - \lambda) \left[e_t(x) - e_t(x_t^s) + (1 - p(\theta_t) \overline{F(x_{t+1}^r)}) [e_t(x_t^s) - e_t(x_{t+1}^r)] \right] \right\}. \quad (14) \end{aligned}$$

Gross flows and transition rates. Gross flows from employment to unemployment represent the total mass of workers separated from a job between two periods:

$$\begin{aligned} EU_{t+1} = & s \left[e_t(x_H) - p(\theta_t)(1 - F(x_{t+1}^r))e_t(x_t^s) \right] \\ & + (1 - s) \left\{ \lambda F(x_{t+1}^r) \left[e_t(x_H) - p(\theta_t) \overline{F(x_{t+1}^r)} e_t(x_t^s) \right] \right. \\ & \left. + (1 - \lambda) e_t(x_{t+1}^r) \left[1 - p(\theta_t) \overline{F(x_{t+1}^r)} \right] \right\} \quad (15) \end{aligned}$$

The job separation rate is then defined as the probability that an employed worker

¹⁴As $S(a_t, x)$ is monotonically increasing in x , the individual productivity threshold $x^r(a_t)$ is unique, and $S(a_t, x) > 0 \forall x > x^r(a_t)$. Appendix C provides a detailed discussion.

in period t is not employed in period $t + 1$: $SR_t = EU_t/[e_{t-1}(x_H)]$. Similarly, the gross unemployment to employment (UE) flow is the total mass of workers who start a new job from unemployment:

$$UE_t = u_{t-1}p(\theta_{t-1})\overline{F(x_{t+1}^r)},$$

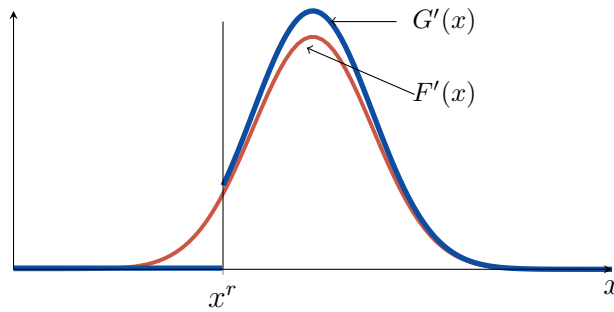
and the job finding rate (JFR) is defined as the probability that an unemployed worker in period t is not unemployed in period $t + 1$: $JFR_t = UE_t/u_{t-1}$. The job-to-job rate (JJR) is measured as the ratio of gross employment to new employment (EE) flows over total employment:

$$JJR_t = \frac{EE_t}{e_{t-1}(x_H)} = \frac{e_{t-1}(x_{t-1}^s)p(\theta_{t-1})[1 - F(x_t^r)]}{e_{t-1}(x_H)}$$

4 Mechanisms for state-dependent fluctuations

The model embeds state-dependent dynamics in labor market variables across two dimensions. First, the response of labor market variables to the productivity shock is stronger in a state with low aggregate productivity. Second, the job separation rate and the unemployment rate are more responsive to a contractionary productivity shock than to an expansionary shock whereas the job finding rate responds symmetrically across shocks.

Figure 2: Distribution for $F'(x)$ and $G'(x)$



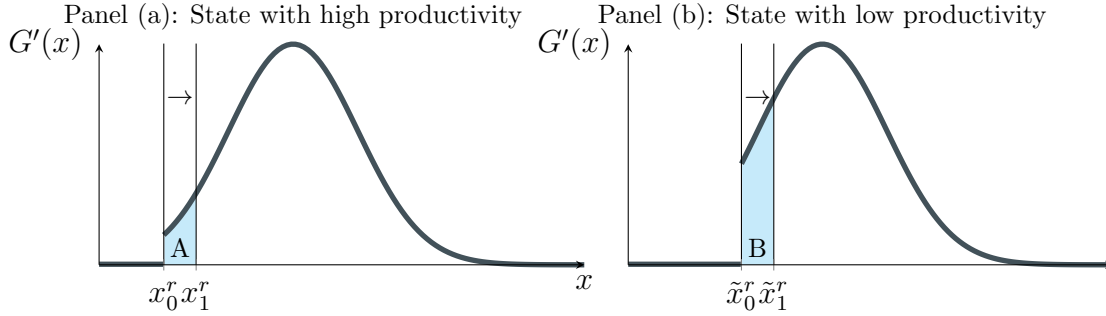
Notes: The figure shows the p.d.f. for $F(x)$ (labelled $F'(x)$, red line) and $G(x)$ (labelled $G'(x)$, blue line).

The distinct responses of labor market variables over states of aggregate productivity is generated by the effect of changes in the individual productivity threshold, $x^r(a)$, on the distributions of individual productivity for newly-established matches, $F(x)$, and for continuing jobs, $G(x)$.¹⁵ Figure 2 shows an illustrative p.d.f. for $F'(x)$ (red line) and

¹⁵To simplify notation, we drop the time index from the distributions. Given the timing assumption

$G'(x)$ (blue line). The critical difference between the two distributions is that $G(x)$ has zero mass below the individual productivity threshold, $x^r(a)$, since jobs with productivity lower than the threshold are terminated whereas $F(x)$ is continuous and twice differentiable since the productivity of new jobs is positively defined across the whole domain of individual productivity.¹⁶ For both distributions, workers whose productivity is below the searching threshold x^s and above $x^r(a)$ search on the job.

Figure 3: States of aggregate productivity and the job separation rate



Notes: An increase of the threshold of individual productivity from \tilde{x}_0^r to \tilde{x}_1^r generates a larger response in the job separation rate in states with low aggregate productivity than an equivalent increase of the threshold of individual productivity from x_0^r to x_1^r in states with high aggregate productivity. The shaded area shows the mass of jobs sensitive to job separation in response to the change in the threshold.

Movements in the individual productivity threshold generate distinct responses in the job separation rate in relation to the state of aggregate productivity. Panel (a) in Figure 3 shows the initial productivity threshold x_0^r on the distribution for continuing jobs $G'(x)$ that is associated with a high level of aggregate productivity.¹⁷ In response to a fall in aggregate productivity, the individual productivity threshold increases from x_0^r to x_1^r , leading to a rise in the job separation rate equal to shaded area A. Panel (b) shows the effect of an equivalent fall in aggregate productivity from an initially low level of aggregate productivity. In this instance, the individual productivity threshold is high and located in the domain of the distribution with high density. The same fall in aggregate productivity increases the individual productivity threshold from \tilde{x}_0^r to \tilde{x}_1^r , leading to a rise in the job separation rate equal to shaded area B, which is larger than area A. Thus, the effect of a shock on the mass of jobs exposed to movements in the individual productivity threshold differs across levels of aggregate productivity, and the

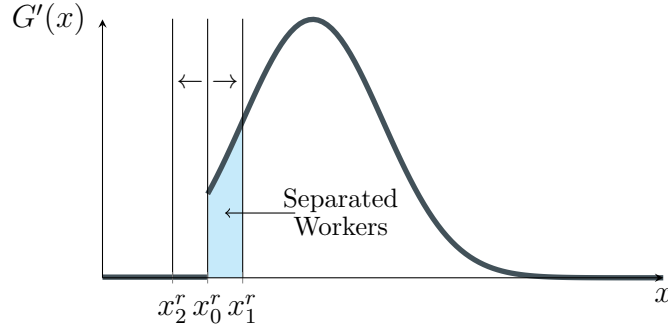
in the model, $G(x)$ refers to $G_{t-1}(x)$ whereas $F(x)$ does not vary with time.

¹⁶We make the standard assumption that $F(x)$ is continuous, twice differentiable and unimodal since it proxies the wage distribution in the data, as examined in Moscarini (2005).

¹⁷Equation (8) implies that a high level of aggregate productivity is associated with a low individual productivity threshold, which is located in a domain of the distribution associated with low density.

response of the job separation rate to the aggregate productivity shock is larger when aggregate productivity is low.¹⁸ By the same principle, the job finding rate may exhibit stronger responses in states with low aggregate productivity. However, these effects turn out to be quantitatively weak, as we discuss in the next section.¹⁹

Figure 4: Contractionary and expansionary shocks and the job separation rate



Notes: The threshold of individual productivity increases (decreases) from x_0^r to x_2^r (x_1^r) in response to contractionary (expansionary) productivity shocks. The shaded area shows the mass of jobs sensitive to job separation in response to a contractionary technology shock.

An important property of the model is the larger response of the job separation rate and the unemployment rate to a contractionary productivity shock compared to an expansionary one. To gain intuition, Figure 4 shows the effect of opposite movements in the threshold on the distribution for continuing jobs $G'(x)$. An increase in the threshold from x_0^r to x_1^r in response to a contraction in aggregate productivity generates the separation of jobs whose productivity is below x_1^r , represented by the shaded area in the figure. On the contrary, a decrease in the threshold from x_0^r to x_2^r in response to an expansion in aggregate productivity involves no job separation since the threshold moves in a region of the distribution with zero mass (i.e. $G(x_2) = 0$). By contrast, while a contractionary productivity shock that increases the threshold sharply raises the job separation rate and the unemployment rate, an expansionary productivity shock that decreases the threshold does not generate an equivalent fall in these variables.²⁰ This distinct reaction to expansionary and contractionary shocks is absent in the job finding rate since the distribution for new hires is positively defined across the domain of $F(x)$.²¹

¹⁸As discussed in Sedláček (2014), a wide range of parameter values retain x^r to the left of the mode of the density function.

¹⁹Appendix D reports a graphical representation of the mechanism underpinning the distinct response of the job finding rate at different levels of productivity.

²⁰The fall in separation only comes through the effect of the change in the reservation threshold on the proportion λ of workers who receive a new shock and on the newly matched job-seekers who now face lower efficiency standards to be hired.

²¹In theory, distinct responses in the job finding rate with respect to the sign of the shock are possible.

5 Model simulation and quantitative results

This section presents the calibration of the model and the quantitative results. It compares simulated moments in the model against those in the data. It investigates the extent to which the model replicates the observed changes in the magnitude of fluctuations at distinct states of aggregate productivity and the skewness of labor market variables. Finally, it presents generalized impulse response functions to isolate the dynamic responses of labor market variables in different states of aggregate productivity (i.e., high versus low) and to contractionary and expansionary shocks.

5.1 Calibration

To allow the theoretical framework to embed state-dependent dynamics, we solve the model non-linearly iterating over the policy function on a discretized state space, following the approach in Tauchen (1986). Appendix E reports the solution procedure.

We calibrate the model at monthly frequency. The discount factor, β , is set equal to $0.953^{(1/12)}$, as in Shimer (2005). The cost of posting a vacancy, κ , is set equal to 0.17 to match the derived calculations on costs of a job opening based on survey results cited in Barron and Bishop (1985) and Barron *et al.* (1997). The flow value of unemployment, b , is set to equal 0.71, as in Hall and Milgrom (2008), which is between the value of 0.4 in Shimer (2005) and the value of 0.95 in Hagedorn and Manovskii (2008). The elasticity of the matching function with respect to vacancies, ϕ , is set equal to 0.5 in the range of empirical estimates in Petrongolo and Pissarides (2001). To satisfy the Hosios (1990) condition, which ensures that the equilibrium of the decentralized economy is Pareto efficient, we assume that the elasticity of labor market tightness with respect to vacancies, η , is equal to the firm's bargaining power, $(1 - \phi)$, i.e., $\eta = (1 - \phi) = 0.5$. The parameter of match efficiency, γ , is set equal to 0.445 to match the empirical average job finding rate of 0.45, as in Hagedorn and Manovskii (2008). The exogenous separation probability, s , is set equal to 0.0105 to match the average job separation rate of 0.03. The probability of receiving a new individual productivity shock, λ , and the variance of individual productivity, σ_x , are set to equal 0.24 and 0.17, respectively, to match the quarterly autocorrelation and standard deviation of the HP-filtered log separation rate, equal to 0.54 and 0.055, respectively. The distribution of individual productivity shocks is a truncated log-normal density function with the lower bound equal to zero

The fall in job creation from an increase in the reservation threshold need not be as large as a fall due to an equal decrease in the reservation threshold. In our model, we find that this effect is extremely small and the size of responses in the job finding rate is almost identical across contractionary and expansionary shocks.

(i.e., $x_L = 0$) and the upper bound set to have less than 1 percent of the mass of the distribution above it (i.e., $x_H = 1.55$). The mean of the log distribution of individual productivity, μ_x , is set to equal -0.087 to normalize the long-run average productivity in the economy to 1. The cost of searching on the job, k^s , is set to equal 0.128 to match the mean monthly job-to-job transition rate of 3.2, calculated from the CPS data, as in Fujita and Ramey (2012). The autoregressive parameter, ρ , and the standard deviation, σ , of the aggregate productivity process are set equal to 0.973 and 0.0068, respectively, to match the autocorrelation and standard deviation of HP-filtered log labor productivity at quarterly frequency, as in Hagedorn and Manovskii (2008). Table 5 summarizes the calibration of parameters. Table E.1 in Appendix E shows that the simulated targeted moments are close to the empirical counterparts in the data.

Table 5: Parameter values

Parameter	Description	Value
β	Discount factor	0.953 ^(1/12)
κ	Vacancy cost	0.17
κ_s	OJS cost	0.128
b	Flow value of unemployment	0.71
η	Elasticity of matching with respect to vacancies	0.5
γ	Matching function efficiency parameter	0.445
ϕ	Worker's bargaining power	0.5
s	Exogenous job separation rate	0.0105
λ	Arrival rate of individual productivity shocks	0.24
x_L	Lower bound of individual productivity shocks	0
x_H	Upper bound of individual productivity shocks	1.55
μ_x	Mean of log individual productivity shocks	-0.087
σ_x	Standard deviation of individual productivity shocks	0.17
ρ	Persistence parameter of aggregate productivity	0.973
σ	Standard deviation of aggregate productivity shocks	0.0068

5.2 Business cycle statistics

Table 6 compares the standard deviation, the correlation coefficient with productivity, and the autocorrelation coefficient for selected variables in the data (top panel) against the corresponding statistics in the simulated model (bottom panel). The moments are based on a set of 1,000 simulations of the same length as the empirical data. The model accurately reproduces the standard deviation of output 0.021 in the data. The

simulated standard deviation of unemployment and the job finding rate of 0.101 and 0.063, respectively, are very close to those in the data (0.137 and 0.089, respectively). The simulated standard deviation of vacancies, equalling 0.040, is approximately three times smaller than the value of 0.138 in the data. Likewise, the simulated standard deviation of vacancy-to-unemployment ratio (v/u) equal to 0.137 is approximately half the value in the data.²²

The model replicates accurately the sign of the correlation coefficient of the variables with productivity. The unemployment rate and the job separation rate are negatively correlated with productivity whereas the rest of the variables are positively correlated. The correlations in the model are larger than those in the data since productivity shocks are the only exogenous source of aggregate fluctuations. It is worth noting that in the model productivity is positively correlated with vacancies and negatively correlated with the unemployment rate, which replicates important stylized facts in the data (i.e., the Beveridge curve).²³ Finally, the autocorrelation coefficients for most variables in the model are similar to those in the data.

5.3 State-dependent fluctuation and skewness

This section assesses whether the model is able to replicate the distinct responses of labor market variables related with the different states of aggregate productivity and evaluates the degree of skewness in the model.

Table 7 shows the standard deviations of simulated labor market variables in levels (columns (1)-(3)) and growth rates (columns (4)-(6)) associated with productivity below and above its median value. Columns (1) and (2) shows that the standard deviations of the simulated variables are larger in periods of productivity below the median value. Column (3) shows the relative standard deviation between the variance of the variables when productivity is below and above the median value. The entries show that all the variables, except the job finding rate, have larger fluctuations in periods with low aggregate productivity. Once again, the result is substantially smaller for the job finding

²²The relatively larger fluctuations of the job finding rate compared to vacancies indicate that in the model the productivity threshold x_t^r rather than posting vacancies is the main channel through which firms adjust their recruiting decisions. Firms adjust x_t^r to determine endogenous separation, which also affects the expected value of new matches. The adjustment in reservation productivity mitigates the fluctuations in the expected surplus of new matches and hence dampens the response of vacancies.

²³As discussed by Fujita and Ramey (2012), OJS is critical for the negative correlation between vacancies and the unemployment rate. In response to a negative productivity shock, unemployment rises sharply but the total mass of job seekers does not change as much because the endogenously separated workers were all in the OJS pool. Was it not for the fall in OJS, firms could have adjusted the v/u ratio downwards while simultaneously increasing vacancies due to the high separation rate.

Table 6: Labor market statistics in the data and the model

Data	p	U	JFR	JSR	E	V	V/U	Y
σ_x	0.013	0.137	0.089	0.055	0.009	0.138	0.262	0.021
$\text{Corr}(p_t, x_t)$	1.000	-0.229	0.212	-0.556	0.232	0.394	0.316	0.661
$\text{Corr}(x_t, x_{t-1})$	0.763	0.891	0.840	0.535	0.899	0.907	0.905	0.843
Model	p	U	JFR	JSR	E	V	V/U	Y
σ_x	0.013	0.101	0.063	0.055	0.008	0.040	0.137	0.021
$\text{Corr}(p_t, x_t)$	1.000	-0.970	0.978	-0.951	0.929	0.927	0.991	0.991
$\text{Corr}(x_t, x_{t-1})$	0.769	0.822	0.781	0.647	0.821	0.586	0.778	0.794

Notes: p is productivity, U is the unemployment rate, JFR is the job finding rate, JSR is the job separation rate, E is the employment rate, V is vacancies, V/U is labor market tightness, and Y is output. The simulated moments are computed as means of 1,000 simulations of 3,968 monthly periods. After discarding the first 200 observations in each simulation, the remaining series are aggregated at quarterly frequency with the same length of the observed series for the period 1950:I-2014:IV.

rate. The relative standard deviation of most variables in levels is within the range of 1.16-1.58, while it is only 1.08 for the job finding rate. A similar result holds for the statistics derived using the growth rates of the variables (columns (4)-(6)). These patterns are similar to those in the data reported in Table 1.

Table 7: Standard deviation of simulated variables for different states of productivity

	Levels			Growth Rates		
	$\sigma_{p < \text{Median}}$ (1)	$\sigma_{p > \text{Median}}$ (2)	$\frac{\sigma_{p < \text{Median}}}{\sigma_{p > \text{Median}}}$ (3)	$\sigma_{p < \text{Median}}$ (4)	$\sigma_{p > \text{Median}}$ (5)	$\frac{\sigma_{p < \text{Median}}}{\sigma_{p > \text{Median}}}$ (6)
Unemployment	0.0921	0.0792	1.17	0.0657	0.0578	1.14
Job Finding Rate	0.0237	0.0222	1.08	0.0188	0.0174	1.08
Separation Rate	0.0017	0.0012	1.41	0.0017	0.0012	1.47
Employment Rate	0.0079	0.0051	1.58	0.0056	0.0035	1.62
Output	0.0188	0.0164	1.16	0.0144	0.0126	1.14
Productivity	0.0112	0.0116	0.978	0.0091	0.0093	0.980

Notes: Entries are averages of 1,000 simulations over 656 monthly periods. After discarding the first 400 observations in each simulation, the remaining series are aggregated at quarterly frequency and have the same length as the period 1950:I-2014:IV.

Table 8 reports the excess skewness of selected variables in the model. The entries show that the model replicates the sign of skewness in the data (see Table 4). In the model

as in the data, the unemployment rate and the job separation rate are positively skewed both in levels and growth rate. The employment and output are negatively skewed. The model generates a low degree of skewness in the job finding rate, which corroborates the empirical findings on the insignificant degree of skewness in the job finding rate in the data. Overall, the coefficients of skewness in the model are lower than those in the data. This difference results from the quarterly aggregation, which averages out differences in the original simulated monthly series. Appendix L shows skewness coefficients for the series at monthly frequencies, which are of similar magnitude to those in the data.

Table 8: Skewness in simulated data

	Levels	Growth rate
Unemployment	0.180	0.159
Job Finding Rate	-0.082	-0.023
Separation Rate	0.519	0.400
Employment	-0.579	-0.195
Output	-0.175	-0.048
Productivity	0.035	0.017

Notes: Entries are averages of 1,000 simulations over 656 monthly periods. After discarding the first 400 observations in each simulation, the remaining series are aggregated at quarterly frequency and have the same length as the period 1950:I-2014:IV.

To summarize, the model replicates reasonably well the different volatility of labor market variables at distinct states of aggregate productivity, and it reproduces accurately the signs of skewness in the data.

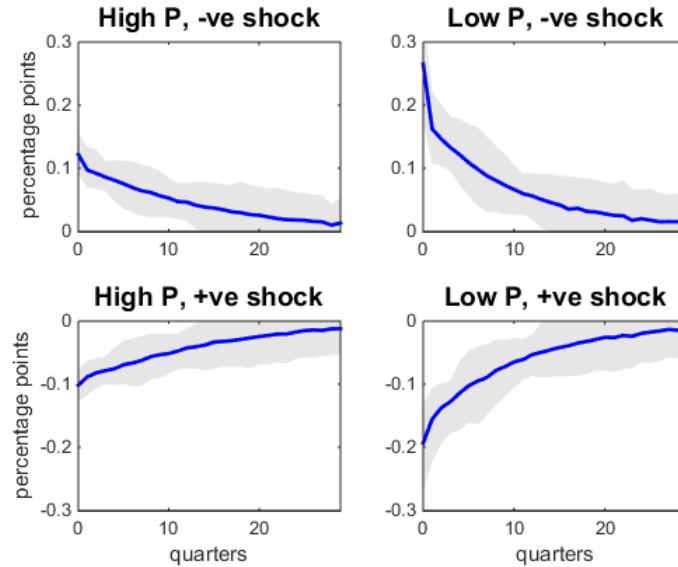
5.4 Dynamic response of labor market variables

To investigate the extent to which the dynamic responses of labor market variables are different across states with high and low aggregate productivity and in response to an expansionary or a contractionary shock, Figures 5-7 plot generalized impulse response functions (IRFs) for the job separation rate, the job finding rate, and the unemployment rate to a productivity shock equal to one quarterly standard deviation (solid line) together with the 5th-95th percentiles (shaded area).²⁴ Each figure reports the response of the variables in states with high and low aggregate productivity (left and right panels,

²⁴Appendix F describes the computational method to derive generalized IRFs.

respectively) and to contractionary and expansionary shocks (bottom and top panels, respectively).²⁵

Figure 5: Responses of the job separation rate across productivity states and shocks



Notes: The solid line represents the mean IRF value in each period. The dashed red lines represent the 5th and 95th percentiles of the IRF values. Responses of the variables in periods with high and low aggregate productivity are in top and bottom panels, respectively. Responses to positive and negative shocks are in left and right panels, respectively. Units on the y-axis are percentage points.

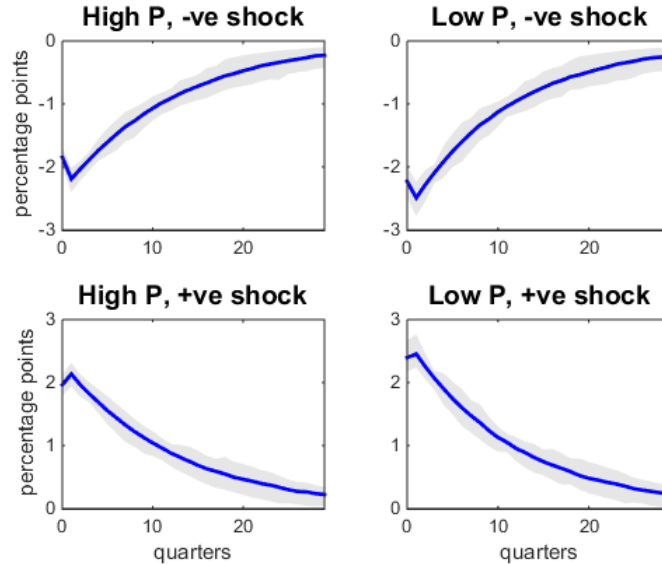
Figure 5 show that the response of the job separation rate is more than twice as large in the state with low productivity compared to the state with high productivity and that responses to a contractionary shock are stronger than those to an expansionary shock, especially in the state with low aggregate productivity. As discussed in Section 4, the mechanism that generates these distinct dynamics is straightforward. The different responses with respect to the state with aggregate productivity (left versus right panels) originate from the effect of shifts in the reservation threshold for individual productivity on the job separation rate. In the state with high aggregate productivity, the threshold is low and located in a region of individual productivity distribution with low density. Aggregate shocks that move the threshold displace a limited number of workers and therefore have a limited effect on the job separation rate. By contrast, in the state with low aggregate productivity, the threshold of individual productivity is high and located in a region of the distribution of individual productivity with high density. Thus, an

²⁵In the simulation, a state with high aggregate productivity is considered to be a quarter in which aggregate productivity is at the 90th percentile. A state with low productivity is a quarter in which aggregate productivity is at the 10th percentile.

identical aggregate productivity shock that moves the threshold similarly, it displaces a larger fraction of workers, thereby generating a large shift in the job separation rate.

The distinct responses in the job separation rate with respect to a contractionary and an expansionary shock (top versus bottom panels) originate from the truncation of the distribution of individual productivity, which has zero mass for values below the reservation threshold since those jobs are inefficient. As discussed in Section 4, a contractionary productivity shock increases the threshold of individual productivity, leading to the termination of jobs with an individual productivity below the threshold. By contrast, an expansionary productivity shock lowers the productivity threshold by relaxing the firms' threshold of individual productivity for efficient matches. The effect on the job separation rate is limited because the individual productivity levels of existing jobs already exceed the individual productivity threshold and workers avoid job separation via OJS. The separation rate falls to the extent that existing jobs receive a new individual productivity, which represents only a fraction λ of all jobs.

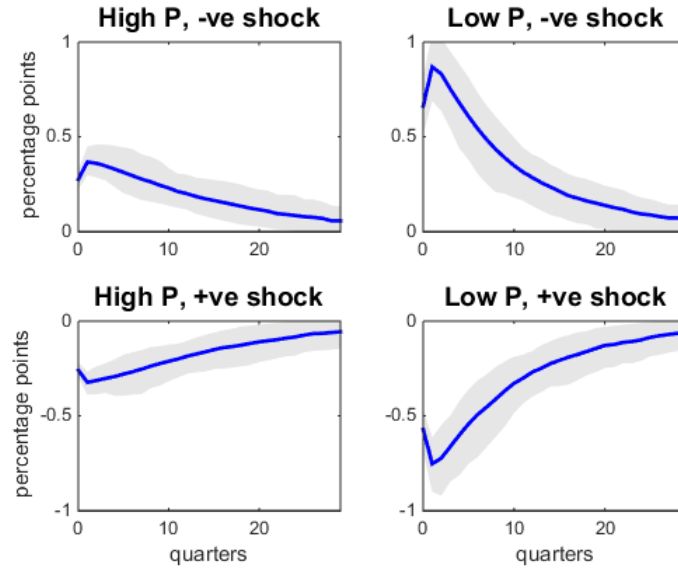
Figure 6: Responses of the job finding rate across productivity states and shocks



Notes: The solid line represents the mean IRF value in each period. The dashed red lines represent the 5th and 95th percentiles of the IRF values. Responses of the variables in periods with high and low aggregate productivity are in top and bottom panels, respectively. Responses to positive and negative shocks are in left and right panels, respectively. Units on the y-axis are percentage points.

Figure 6 shows the responses of the job finding rate. The entries reveal that the job finding rate reacts differently across states with low and high aggregate productivity (left versus right panels) whereas responses are similar across contractionary and expansionary shocks (top versus bottom panels). Consistent with the finding in Section

Figure 7: Responses of the unemployment rate across productivity states and shocks



Notes: The solid line represents the mean IRF value in each period. The dashed red lines represent the 5th and 95th percentiles of the IRF values. Responses of the variables in periods with high and low aggregate productivity are in top and bottom panels, respectively. Responses to positive and negative shocks are in left and right panels, respectively. Units on the y-axis are percentage points.

2, the quantitative differences across states of aggregate productivity are substantially smaller than those for the job separation rate. The more moderate difference in state-dependent fluctuations results from OJS. Movements in OJS counteract fluctuations in the unemployment rate and dampen changes in labor market tightness, therefore limiting the impact of shocks on a firm’s hiring and the job finding rate.²⁶

In Figure 7, the response of the unemployment rate is almost twice as large in the state with low productivity (left versus right panels), with moderate differences in the magnitude of responses across contractionary and expansionary shocks (top versus bottom panels). In the model, the unemployment rate results from changes in the job separation rate and the job finding rate. These responses show that the distinct responses in unemployment are primarily inherited from those in the job separation rate.

²⁶Petrosky-Nadeau and Zhang (2013) show that the DMP model with a constant job separation generates a larger elasticity in the job finding rate during periods of deep recession, driven by the higher sensitivity of the joint surplus of forming a match in periods with low productivity. Our analysis shows that the interaction between endogenous job separation and OJS reduces the elasticity of the job finding rate, because the mass of all job seekers fluctuates less than unemployment and contractionary and expansionary shocks have a similar effect on the job finding rate.

6 State dependence and labor market reforms

This section enriches the model with labor market protection in the form of a layoff tax levied on the dismissal of established jobs. The analysis investigates the effect of the layoff tax on the long-run equilibrium of the model and assesses whether the permanent tax removal in states with low or high aggregate productivity generates critical differences in the transitional dynamics and welfare.

6.1 Introducing layoff taxes

The model described in Section 3 is enriched with a “wasteful” layoff tax, τ , that the firm must pay to cover administrative costs and layoff procedures whenever a worker is (endogenously or exogenously) separated.²⁷ Firms whose workers move to another job with OJS do not incur into the layoff tax. Layoff taxes are not levied on the separation of newly-established matches, and therefore the joint value of an employment relationship for new matches (indexed by N) and continuing matches (indexed by O) are distinct and defined as:

$$M^N(a_t, x) = \max[M^{c,s}(a_t, x), M^{c,n}(a_t, x), U(a_t) + V(a_t)], \quad (16)$$

$$M^O(a_t, x) = \max[M^{c,s}(a_t, x), M^{c,n}(a_t, x), U(a_t) + V(a_t) - \tau], \quad (17)$$

where $M^N(a_t, x)$ and $M^O(a_t, x)$ denote the joint value for new and existing workers, respectively, which account for on-the-job searches. $M^{c,s}(a_t, x)$ and $M^{c,n}(a_t, x)$ are the joint values for continuing the job relationship with or without OJS, respectively, and are defined as:

$$M^{c,n}(a_t, x) = a_t x + \beta \mathbb{E}_t \left\{ U(a_{t+1}) + V(a_{t+1}) - \tau + (1-s) \left[(1-\lambda) S^O(a_t, x) + \lambda \int_{x_L}^{x_H} S^O(a_{t+1}, x') dF(x') \right] \right\}, \quad (18)$$

$$M^{c,s}(a_t, x) = a_t x - k^s + \beta \mathbb{E}_t \left\{ U(a_{t+1}) + V(a_{t+1}) - \tau + \left(1 - p(\theta) \overline{F(x_{t+1}^r)} \right) (1-s) \left[(1-\lambda) S(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S^O(a_{t+1}, x') dF(x') \right] + p(\theta) \phi \int_{x(a_{t+1})}^{x_H} S^O(a_{t+1}, x') dF(x') \right\}. \quad (19)$$

The total surplus equals the value of establishing a match net of the outside options to the worker and the firm. Thus, the value functions for the joint surpluses for new and

²⁷See Fella (2007), Ljungqvist (2002), Postel-Vinay and Turon (2014), and Cozzi and Fella (2016) for a discussion on the role of employment protection measures in matching models.

continuing jobs are:

$$S^N(a_t, x) = \max[S^{N,c}(a_t, x), 0], \quad (20)$$

$$S^O(a_t, x) = \max[S^{O,c}(a_t, x), 0], \quad (21)$$

where $S^{N,c}(a, x)$ and $S^{O,c}(a, x)$ represent the total surpluses in case the worker and the firm establish a new match or continue an existing job relationship, respectively, accounting for the optimal choice of OJS. The total surpluses for new and old matches, without and with OJS are:

$$S^{N,n}(a_t, x) = a_t x - b + \beta \mathbb{E}_t \left\{ (1-s) \left[(1-\lambda) S^O(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S^O(a_{t+1}, x') dF(x') \right] - \tau - p(\theta_t) \phi \int_{x_L}^{x_H} S^N(a_{t+1}, x') dF(x') \right\}, \quad (22)$$

$$S^{N,s}(a_t, x) = a_t x - k^s - b + \beta \mathbb{E}_t \left\{ \left[1 - p(\theta) \overline{F(x_{t+1}^r)} \right] (1-s) \left[(1-\lambda) S^O(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S^O(a_{t+1}, x') dF(x') \right] - \tau \right\}, \quad (23)$$

$$S^{O,n}(a_t, x) = S^{N,n}(a_t, x) + \tau, \quad (24)$$

$$S^{O,s}(a_t, x) = S^{N,c}(a_t, x) + \tau. \quad (25)$$

Equations (22) and (23) show that the surpluses of newly-established job relations (with or without OJS) are reduced by the expected layoff tax if the job is dismissed in the future. Equations (24) and (25) show that the surpluses for existing job relations (with or without OJS) entail an intertemporal tradeoff between the benefit of foregoing tax payment if the job is not severed in the present period t and the cost of having to pay the layoff tax if the worker is dismissed in the future. Important for our analysis, the difference in the surpluses for newly-hired and existing workers generates distinct thresholds of individual productivity. The reservation productivity at which new matches become inefficient is higher than the reservation threshold for existing workers because firms are not discouraged from discontinuing the newly-formed match at time t as they are for incumbent workers. Consequently, the firm retains existing workers with individual productivity in the range $x \in (x_t^{r,O}(a), x_t^{r,N}(a)]$ but fails hire new matches with individual productivity in the same interval. Within this range of individual productivity, it is inefficient to pay layoff taxes to dismiss existing workers, but it is efficient to refuse new matches to which layoff taxes do not apply.

A worker's decision to search on the job is influenced by the prospects of obtaining a successful match. The productivity threshold that applies to this expectation, and hence

to the decision to search on the job, is $x_t^{r,N}(a)$ since employed and unemployed job seekers are identical to the firm. Additionally, the cutoff level for OJS is the same across new and incumbent workers.²⁸ Appendix G outlines the laws of motion of employment in the presence of layoff taxes.

6.2 The long-run effect of layoff taxes

We set the value for the layoff tax equivalent to 15 percent of average monthly productivity ($\tau = 0.15$), which makes the tax approximately equivalent to 5 percent of average quarterly wages, as in Llosa *et al.* (2014). Table 9 compares the long-run values of key labor market variables in the version of the model without (column (1)) and with (column (2)) layoff taxes. The tax increases the long-run unemployment rate by two percentage points from 6.8 percent to 8.7 percent, as a result of the large fall in the job finding rate and the broadly constant rate of job separation. The effect of the tax on the long-run value of the job separation rate is limited. The reason is straightforward. While introducing the tax slightly decreases the efficiency threshold for continuing jobs and therefore decreases endogenous separation, it also increases the efficiency threshold for new jobs and therefore discourages OJS. Overall, OJS decreases from 6.6 percent to 3.4 percent, leaving a greater fraction of workers subject to job separation. These two opposing forces offset each other, and the job separation rate declines only by 0.02 percentage points in the long run.

The tax approximately lowers the job finding rate from 44.5 percent to 32.4 percent. The fall in the job finding rate originates from the increase in the threshold of efficient matches for new hires ($x_t^{r,N}(a)$). The higher productivity threshold for new matches discourages on-the-job searches and consequently reduces the total number of job seekers, increasing the search costs accrued to firms, which reacts by decreasing vacancy postings across states of aggregate productivity. Thus, the reduction in OJS amplifies the contractionary effect of the layoff tax on the job finding rate and generates a large rise in the unemployment rate.

The model involves a positive relation between layoff taxes and the unemployment rate in the long run. There is no established consensus on the effect of layoff taxes on the unemployment rate in the literature.²⁹ Mortensen and Pissarides (1999) show that

²⁸Given that the tax (and future taxes) enter linearly into both the surplus from searching and not searching, as seen in equations (22)-(25), the threshold level for OJS x^s that satisfies $S^{N,n}(a_t, x) = S^{N,s}(a_t, x)$ is the same as that which satisfies $S^{O,n}(a_t, x) = S^{O,s}(a_t, x)$.

²⁹See Nickell *et al.* (2005) and references therein for a review on the literature. A recent study by Bentolila *et al.* (2012) documents that changes in firing costs have a different impact on unemployment in different economies.

layoff taxes reduce incentives both to create and destroy jobs and the net effect of these forces on labor market tightness is ambiguous. Ljungqvist (2002) shows that the effect of layoff taxes on unemployment depends on theoretical setups rather than alternative calibrations. We contribute to this realm of research by showing that OJS plays a critical role for the effect of layoff taxes on the unemployment rate.³⁰

Table 9: The long-run effects of a layoff tax

	Baseline $\tau = 0$ (1)	Layoff tax $\tau = 0.15$ (2)
Unemployment rate	0.068	0.087
Job finding rate	0.445	0.324
Separation Rate	0.030	0.030
Job-to-job rate	0.032	0.012
On-the-job search	0.066	0.034
Employment Rate	0.932	0.913
Vacancies	0.179	0.158
V/U	2.832	1.919
Productivity	1.000	1.004

Notes: Entries show long-run averages of labor market variables in the baseline model ($\tau = 0$) and in the alternative model with layoff taxes ($\tau = 0.15$).

6.3 Short-run effects and welfare of layoff tax removal

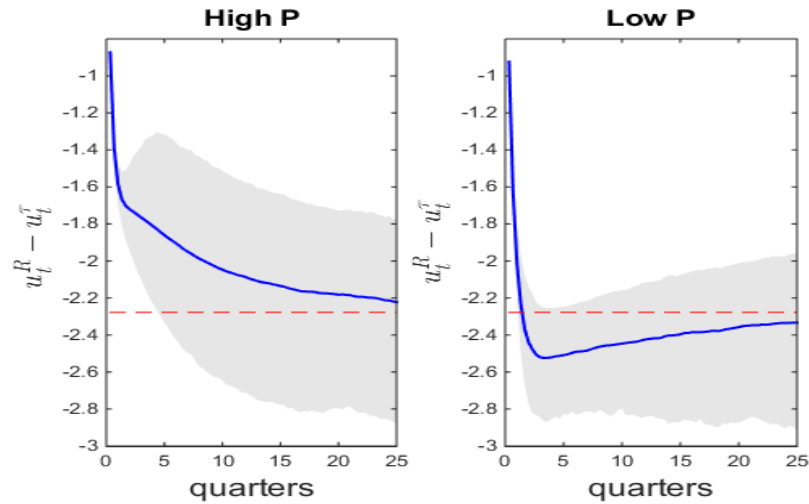
This section investigates whether the timing of an unexpected, permanent removal of the layoff tax enacted in alternative states of aggregate productivity is critical for transitional dynamics and welfare. We compare the effect of the reform enacted at a level of labor productivity below the 10th percentile and above the 90th.

Figure 8 shows transitional paths for the unemployment rate (solid line) that results from the removal of the layoff tax in the low productivity state (left panel) and the high productivity state (right panel), together with the 10th-90th percentiles of the differences

³⁰In this respect, our findings relate to those in Postel-Vinay and Turon (2014) who develop a search and matching model with on-the-job search and renegotiation over severance packages that generates a negative relation between layoff taxes and the unemployment rate. Our analysis builds on the standard DMP model enriched with OJS. The aforementioned study enriches the standard DMP model across several dimensions, assuming wage renegotiation based on mutual consent, endogenous severance packages, and a minimum wage. The opposite result on the effect of layoff taxes on the unemployment rate results from the interaction of the layoff tax with on-the-job searches and minimum wages.

across states (shaded area).³¹ The dashed line shows the long-run difference between the unemployment rate in the economy with the tax eliminated in the first period and the economy with the tax always in place.³² In the long run, the tax removal leads to a similar fall in the average unemployment rate of approximately 2.2 percentage points across states with initially low and high aggregate productivity since both economies converge to the equilibrium over the long run. In the first period of the reform, the unemployment rate falls by approximately 1 percentage point in both initial states of aggregate productivity. However, in the subsequent periods, the transitional dynamics of the unemployment rate differ significantly across states of aggregate productivity. In the state with high productivity, the reform causes the unemployment rate to gradually decrease towards its long-run equilibrium whereas in the state with low productivity, the decline of unemployment is immediate, and the unemployment rate remains below its long-run equilibrium for a protracted number of periods.

Figure 8: Transition path of the unemployment rate to a permanent elimination of the layoff tax



Notes: The solid blue lines represent the average difference in the unemployment rate (in percentage points) of the economy where at time 0 the layoff tax was abolished from that of the same economy where the tax persists from 2,000 simulations of the model. The shaded grey area represents the 10th-90th percentile interval of the differences. The dashed red line represents the long-run average difference between the two economies.

³¹The transition path of unemployment from the outset of the reform at time t is computed as $TP(u_t|e_0(x), \{a_t\}_0^t) = u_t^R - u_t^\tau$, where the superscripts R and τ indicate the reform and tax scenario, respectively, assuming an initial state $e_0(x)$ and a productivity sequence $\{a_t\}_0^t$. Appendix H discusses the simulation procedure.

³²The reported long-run difference of -2.3 is slightly different from the value reported in Table 9 since the value in the table is computed using a set of short simulations equivalent to the 1950-2014 period, as explained in Appendix E. Meanwhile, the dotted line in the figures is the long-run mean-difference between the two economies taken as the average difference after 25 quarters.

To interpret these sharp differences in the transitional paths of the unemployment rate across states of aggregate productivity, we consider the transitional dynamics of the job finding rate, the job separation rate, the job-to-job finding rate and vacancy posting to the tax removal across states of aggregate productivity.³³ The tax removal has a limited effect on the job separation rate across states of aggregate productivity. The reason is straightforward. While removing the tax raises the individual productivity threshold and therefore increases endogenous job separation, it also increases OJS, which enables workers to avoid endogenous separation by moving to a new job. These two opposing forces offset each other and leave the overall response of the job separation rate broadly unchanged across states of aggregate productivity.³⁴ Meanwhile, the fall of the individual productivity threshold for new matches stimulates OJS and increases the pool of job seekers. This force reduces the firm's search cost of filling a vacancy, which leads to a sharp increase in the number of vacancies and the job finding rate on impact.³⁵ In the aftermath of tax reform, the job finding rate immediately rises in both states of aggregate productivity. In the high-productivity state, the job-finding rate overshoots the long-run equilibrium while in the low-productivity state, the rate gradually rises towards the long-run equilibrium. This critical difference originates from the larger surplus of forming a job relation in the high-productivity state, which leads the firm to strongly post vacancies in the period of the tax removal to gain enhanced benefits from forming a job while productivity is high. However, since the initial unemployment is higher in the low-productivity state as a result of the high job separation rate, even a small rise in the job finding rate yields a large fall in unemployment in the state with low productivity, as depicted in the right entry in Figure 8.

How do these sharp differences in the dynamic responses of labor market variables influence welfare across states of aggregate productivity? The tax removal unambiguously increases welfare in the long run since firms stop paying the wasteful tax. Resource allocation becomes efficient since the firm terminates the low-productive jobs it had retained to avoid the payment of the layoff tax, and it recruits high-productive workers whose hiring was prevented in anticipation of payment of the tax in future periods.

In the short run, however, the timing of the reform is critical for welfare since the

³³Appendix I shows the transitional dynamics of these variables.

³⁴The short-run dynamics include an immediate rise in separation due to the increase in x^r , followed by a fall due to the rise in OJS. Quantitatively, both effects are small and similar across initial states.

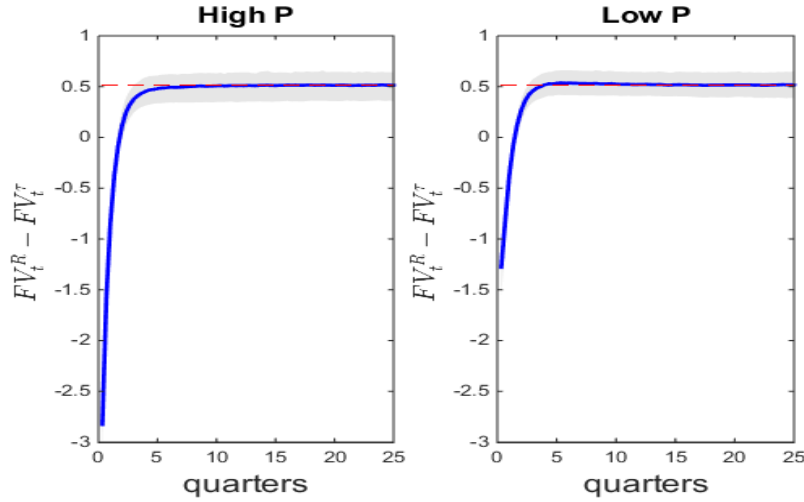
³⁵The job-to-job rate shows a small increase on impact since in period t , the mass of OJS workers is predetermined in period $t - 1$, but the probability of having a successful match is determined by the current fall in the threshold. The job-to-job rate sharply increases in period $t + 1$ when a large number of newly employed workers search on the job. The rise in the mass of OJS workers rapidly stabilizes to its long-run value.

transitional dynamics of labor market variables is notably different across distinct states of aggregate productivity.³⁶ To investigate the relevance in the timing of structural reforms, we proxy welfare with the flow value of the economy that comprises output, the flow value of unemployment net of hiring costs, OJS costs and layoff taxes.³⁷ It is straightforward to derive the welfare gain of the tax removal by subtracting the flow value of the economy with the layoff tax from the flow value of the economy without the tax:

$$\Delta FV_t = \left(a_t \int_{x_L}^{x_H} x de_t^R(x) + bu_t^R - kv_t^R - k^s \phi_t^R \right) - \left(a_t \int_{x_L}^{x_H} x de_t^\tau(x) + bu_t^\tau - kv_t^\tau - k^s \phi_t^\tau - EU_t^\tau \tau \right), \quad (26)$$

where the superscript R indicates variables in the economy with tax reform and the superscript τ indicates variables in the economy with the layoff tax. Equation (26) tracks the welfare gain of the tax removal during each period t .

Figure 9: Transition path of the aggregate flow value to a permanent elimination of the layoff tax



Notes: The solid blue lines represent the average difference in the aggregate flow value of the economy where at time 0 the layoff tax was abolished from that of the same economy where the tax persists from 2,000 simulations of the model. The shaded grey area represents the 10th-90th percentile interval of the differences. The dashed red line represents the long-run average difference between the two economies.

Figure 9 plots equation (26) for the initial 25 quarters and shows the net welfare gains from the removal of the layoff tax for the state with high and low aggregate productivity

³⁶See Millard and Mortensen (1997), Cacciatore and Fiori (2016), Cacciatore *et al.* (2016) and Poilly and Wesselbaum (2014) for a welfare analysis on the effect of layoff taxes in search and matching models.

³⁷See Ljungqvist and Sargent (2012) for a similar approach to approximate welfare.

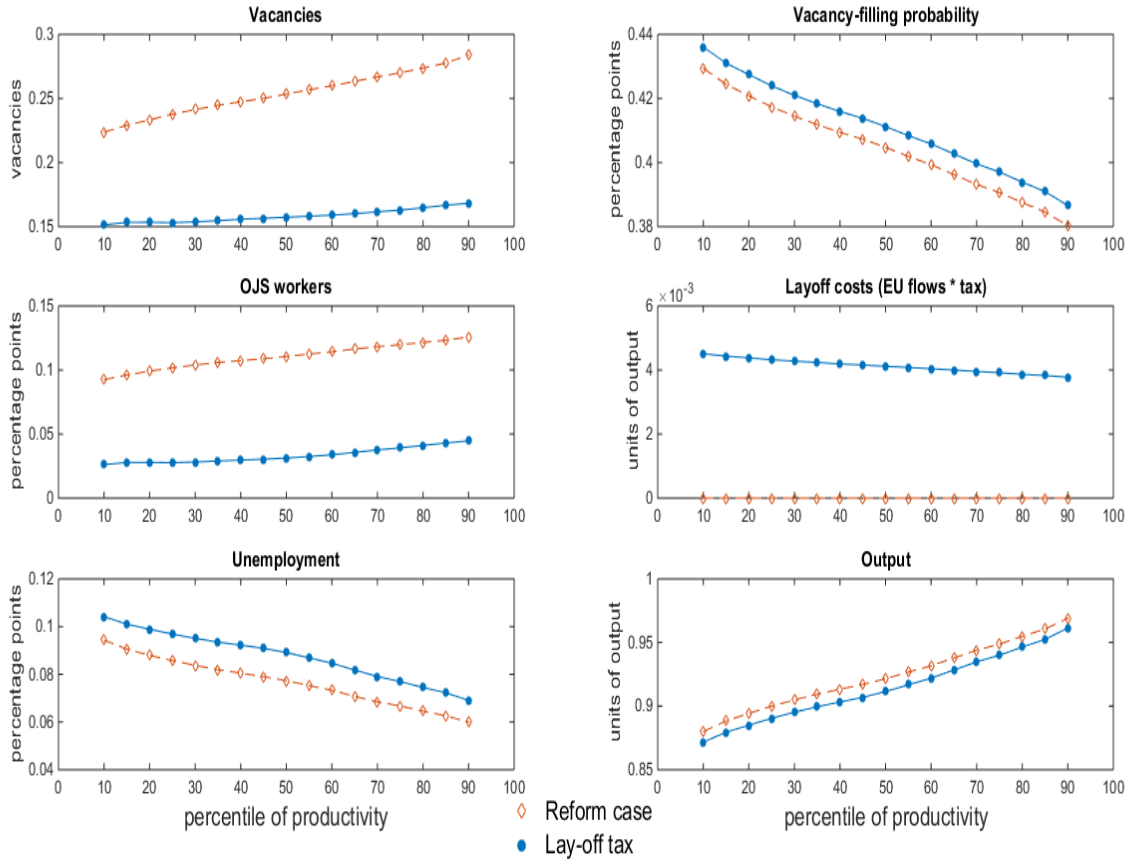
(left and right panels, respectively). A tax removal generates a contemporaneous welfare loss approximately twice as large in the state with high productivity compared to the state with low aggregate productivity. When the reform is enacted in the state with high aggregate productivity, the welfare loss is equal to a reduction of approximately 2.8 units in the flow value of the economy, compared to the reduction of approximately 1.2 units in the state with low aggregate productivity.³⁸ Welfare losses are short lived across different states of aggregate productivity as they disappear after four quarters once the economy reaches its long-run equilibrium. Over the long run, the welfare gain from the reform is equivalent to approximately 0.5 welfare units, as indicated by the dashed red line. We use equation (26) to derive an overall measure of welfare gain from the tax removal by deriving the present discounted gain from the tax removal (i.e. the weighed discounted sum of futures flow values, $\sum_0^\infty \beta \mathbb{E}_0\{\Delta FV_t\}$). We find that the flow value associated with the implementation of the tax removal during periods with low productivity is 3.5 percent larger than the value associated with the same reform enacted in states with high aggregate productivity.

The analysis reveals that state dependence in labor market fluctuations is critical for welfare and the tax removal involves sharp welfare losses in the first period of the reform. Thereafter the benefits quickly outweigh the costs. To identify the sources of welfare losses in the first period of the tax removal, Figure 10 compares the mean of selected variables in the economy with the layoff tax (circle line) against the mean of the same variables in the first period of the tax removal (diamond line) over the percentiles of the distribution of aggregate productivity. The difference between the lines isolates the effect of the tax removal on each variable at each percentile of aggregate productivity. The reform generates an immediate rise in output and fall in the unemployment rate that are proportional across distinct percentiles of aggregate productivity. Instead, the strength in the responses of vacancy posting and the mass of workers searching on the job increase with the level of aggregate productivity. The reason is intuitive. The incentive for the firm and worker to establish a new job relation depends on the joint surplus of forming a match, which increases with the level of aggregate productivity. Therefore search efforts increase proportionally to the level of aggregate productivity. The benefits directly related to the elimination of firing costs only vary moderately across percentiles of aggregate productivity, as depicted in the center-right diagram in the figure.

Overall, the analysis shows that tax removal involves important short-run tradeoffs mainly related to the deadweight losses in search costs that are considerably larger in

³⁸The flow value of welfare is implicitly normalized by marginal utility of consumption, which is equal to 1 since preferences are linear in consumption.

Figure 10: Vacancies, vacancy-matching probability, on-the-job search, gross job destruction (EU flows), unemployment, and output over the distribution of labor productivity



Notes. Blue solid circles represent average levels of the given variable at the respective percentile of labor productivity. Red empty diamonds represent the average instantaneous level of the same variable when the unannounced tax reform occurs (i.e. $\tau = 0$) at the respective productivity percentile. The values are computed from a simulation of 3,000 monthly periods (1,000 quarters).

states with high aggregate productivity. The timing of the labor market reforms is critical. The tax elimination in states with low productivity involves higher short-run welfare gains than during states with high aggregate productivity. Over the long run, labor market reform is welfare enhancing across states of aggregate productivity.

7 Conclusion

This paper isolates important state dependence in labor market fluctuation over the business cycle. The volatility of the unemployment rate and the job separation rate is larger in periods with low productivity. A DMP model enriched with endogenous job

separation and on-the-job search encompasses powerful state dependence and replicates these empirical regularities well. Our application establishes critical differences of labor market reforms enacted in distinct states of the economy for the transitional dynamics of labor market variables and welfare.

The analysis may be extended across several dimensions. The mechanism of state dependence based on endogenous job separation may be recast in a comprehensive model that accounts for a broader range of real and nominal rigidities that are needed to replicate several business cycle properties in the data. The more general framework may unveil important interactions between state dependence of labor market dynamics and a broad set of macroeconomic variables. This will prove challenging, however, because it requires a non-linear solution to a complex model. It would also be interesting to use the framework to study the design of optimal labor market reforms. Future work could extend the analysis to determine the optimal provision of labor market reforms at different states of productivity and in response to contractionary and expansionary shocks. The analysis can be further extended to assess a wide range of labor market institutions (i.e. unemployment benefits, labor taxes and hiring subsidies among others) to provide a comprehensive appraisal of the welfare implication of alternative labor market reforms. These investigations remain outstanding tasks for future research.

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Appendix

A Data sources

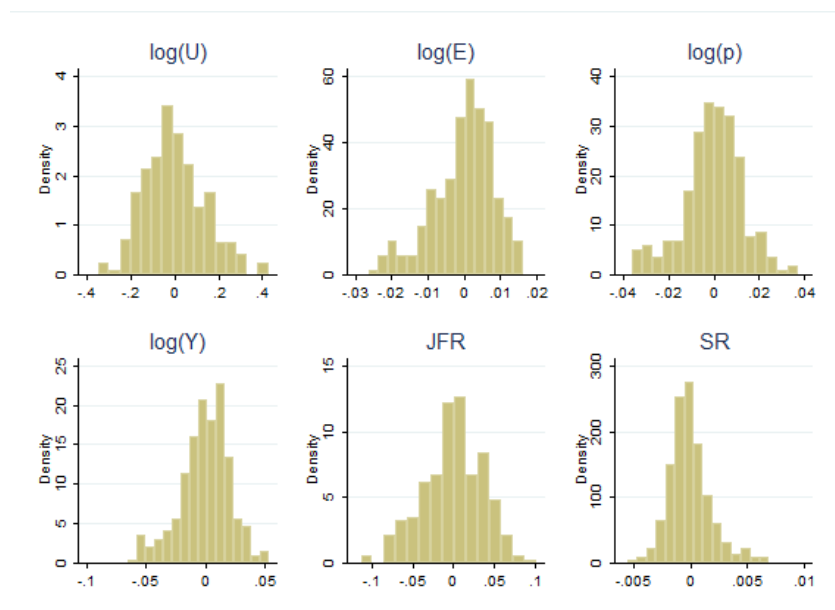
The analysis uses the following time series: real Gross Domestic Product (GDP), average labor productivity, the unemployment rate, vacancies, the job finding rate, the separation rate. GDP is the non-farm business output as provided by the Bureau of Labor Statistics (BLS), while labor productivity is output per worker in the non-farm business sector. Both series were downloaded from Federal Reserve Bank of St. Louis Database (FRED). Unemployment is also provided by the BLS via FRED. The monthly job separation and job finding probabilities are computed following the continuous-time adjustment proposed by Shimer (2012). While we leave the details to the original paper, the essence of continuous time adjustment is to estimate the transition probabilities between unemployment and employment as discrete time probabilities derived from continuous-time hazard rates that are assumed to be constant within each month. This method controls for the bias of simultaneously estimating two related discrete probabilities. We used the original series provided on Rober Shimer's web page from 1950 to 2007, and extend them using the BLS data until 2014. The monthly series are then averaged over the respective quarters.

B Data distribution

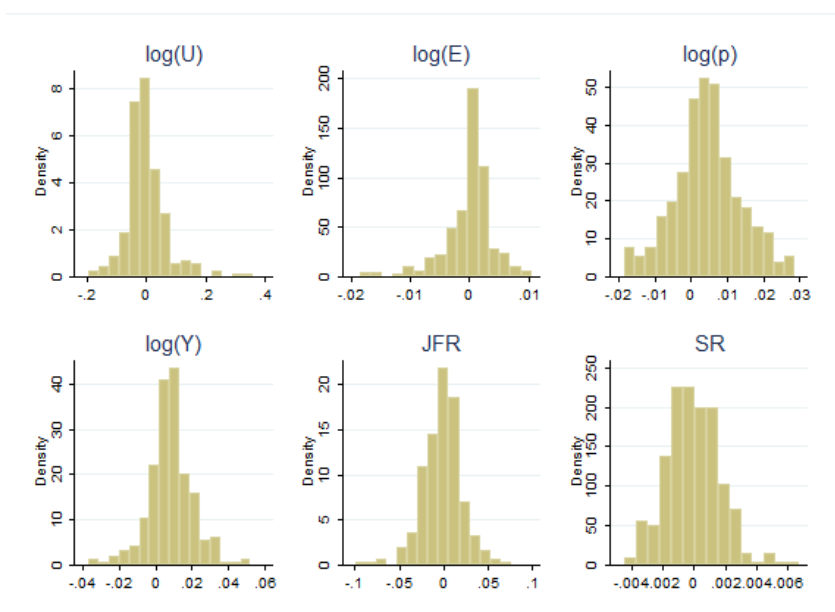
Figure B.1a shows the distribution of quarterly averages in the levels (top panel) and growth rates (bottom panel) of the unemployment rate, the employment rate, productivity, output, the job finding rate and the job separation rate over the sample period. The unemployment rate is positively skewed both in levels and growth rates and similarly the employment rate is negatively-skewed. The separation rate is positively skewed both in levels and growth rates. The distribution of the job finding rate shows a slightly negative skewness in levels, which disappears in growth rates. A similar result holds for average labor productivity.

Figure B.1: Empirical skewness of labor market variables

(a) Histograms of quarterly averages for the period 1950:I-2014:IV.



(b) Histograms of quarterly growth rates averages for the period 1950:I-2014:IV.



Notes: U is the log unemployment rate, E is the log employment rate, p is log labor productivity, Y is log output, JFR is the job finding rate, SR is the job separation rate. Level variables are HP filtered with a smoothing parameter equal to 1,600. Growth rates are computed as log differences of quarterly averages Appendix A provides data sources.

C Uniqueness of productivity threshold $x^r(a_t)$

Assuimng the threshold for OJS $x^s(a)$ lies above the threshold $x^r(a)$, and setting $S^s(a, z) = 0$, we can rearrange (10) into

$$b + k^s = a_t x_t^r + \beta \mathbb{E}_t \left\{ (1-s) \left(1 - p(\theta_t) \overline{F(x_{t+1}^r)} \right) \left((1-\lambda) S(a_{t+1}, x) + \lambda \int_{x_L}^{x_H} S(a_{t+1}, x') dF(x') \right) \right\}$$

The first term on the RHS is continuous, strictly increasing, and bounded below in x over the support $[x_L, x_H]$. For a given θ_t the term $\left(1 - p(\theta_t)(1 - F(x^r)) \right)$ is continuous and strictly increasing in x . By the properties of $S(a, x)$, the second term on the RHS is bounded below by 0 and is continuous and weakly increasing in x . Therefore, the RHS is bounded below by 0, strictly increasing and continuous in x . These conditions are sufficient for the uniqueness of the value $x^r(a_t)$. Furthermore, as the LHS of the equation is constant, and $S(a, x)$ is increasing in a , then $x^r(a)$ must be decreasing in a .

The proof easily extends to the two cutoffs in the model with layoff taxes, as the layoff tax merely imply adding the tax terms to the LHS.

D Job finding rate and asymmetry with respect to the state of the economy: a graphic example

Figure D.1: Illustrative diagram of the mechanism driving asymmetries with respect to state of the economy in the job finding rate.

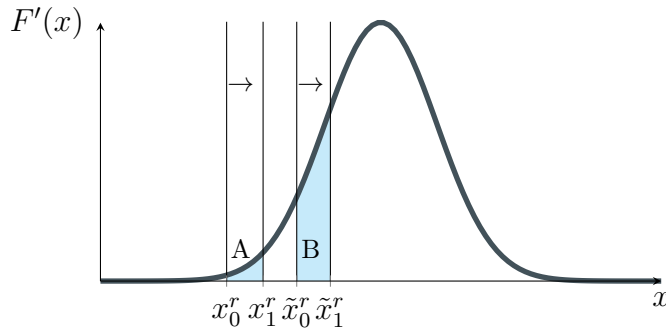


Figure D.1 shows the effect of a movement in the individual productivity threshold on the p.d.f. for new workers, $F'(x)$, at different levels of productivity. The figure shows that the mass of jobs sensitive to movements in the individual productivity threshold depends on the location in the support of the distribution of individual productivity shocks. The closer the productivity threshold is to the mode of the density function, the larger the mass of separations generated by an increase in the reservation threshold. For this reason, the mass of existing workers and new matches affected by movements

in the reservation threshold are larger when the threshold is already high (i.e. when unemployment is high). The figure shows that for the same increase in the reservation threshold from x_0^r to x_1^r and from \tilde{x}_0^r to \tilde{x}_1^r , respectively, the increase in the cumulative density function is lower when the threshold is low (shaded area A) compared to when it is high (shaded area B). Thus, the effect of a shock on the mass of jobs exposed to movements in the threshold is different across different levels of unemployment.³⁹

E Solution of the model and targeted moments

We solve the model nonlinearly using an iterative procedure. To generate an accurate solution, we set the number of grid points of the state space to 45 for the discretized AR(1) process a_t , following the approach described in Tauchen (1986), and 800 for the individual productivity x . The iteration starts with a guess for the policy function of the market tightness $\theta^{(0)}(a)$. Using the guess, we compute the match surplus for all values of x and a and derive the individual productivity threshold $x^r(a)$ and the OJS threshold $x^s(a)$. Using these results, $\theta^{(1)}(a)$ is computed through the free entry condition and used again to compute the surplus. The process is repeated until the norm of $\|\theta^{(0)}(x) - \theta^{(1)}(x)\|$ is below a chosen critical value.⁴⁰ Using the result from Pissarides (2000), under a linear production function, hiring and layoff decisions do not depend neither on the aggregate level of employment nor on the distribution of individual productivity. Hence, the only relevant state variable for the policy function is the aggregate productivity factor.

Table E.1: Model targets

	Target	Model
Job finding rate - mean	0.45	0.442
Separation rate - mean	0.03	0.0308
Separation rate - standard deviation	0.055	0.0545
Separation rate autocorrelation	0.535	0.647
Job-to-job rate - mean	0.032	0.032
Productivity - mean	1	1.001
Productivity - standard deviation	0.013	0.013
Productivity - autocorrelation	0.757	0.7691

Notes: The moments are computed as the means of 1,000 simulations of 3968 monthly periods. After discarding the first 200 observations in each simulation, the remaining series are aggregated at quarterly frequency and have the same length as the period 1950:I-2014:IV.

³⁹Note that this mechanism holds to the extent that $x^r(a)$ lies in the region of the domain of x where $F''(x) > 0$. In such cases, changes in the individual productivity threshold affect a larger proportion of workers when the equilibrium individual productivity threshold is higher.

⁴⁰The value we use is 10^{-8} .

F Computation of Generalized IRFs

We resort to numerical simulations of the model to produce the response of the variables at different points in the state space. To implement the computation, it is critical to establish the starting points for the IRFs, which we describe below together with the procedure used to compute the IRFs.

After obtaining the firm’s policy functions for job separation and job finding rates, we simulate the model for 10,000 monthly periods by generating a random sequence of the Markov process for productivity and then computing the relevant policy variables and state variables.⁴¹ We then obtain the stationary distribution of labor productivity and compute the 10th and 90th percentiles. We split the simulated time series into two samples. The first sample includes all of the periods in which productivity is equal to 10th percentile: this is the “bad-times” sample. The second sample includes all period in which productivity is equal to the 90th percentile: this is the “good-times” sample. For each observation in a given sample, we collect the following variables: u_t , a_t , $e_t(x)$ and $e_{t-1}(x)$. We compute four IRFs as combinations of the following conditions: productivity is either “high” or “low”, and the economy is hit by either a positive or a negative one-standard deviation productivity shock.

Each IRF is obtained through a series of 1,000 simulations. As a starting point for each simulation, we draw a random observation from the relevant sample (either “bad” or “good”) with replacement: $\{u_0, a_0, e_0(x), e_{-1}(x)\}$. We then simulate a continuous Markov path of productivity from the preset starting value a_0 to a_T , where $T = 90$ months. We compute corresponding values of $\{u_t, e_t(x), sr_t, jfr_t, jjr_t\}_{t=0}^T$, where sr_t is the separations rate, jfr_t the job finding rate, and jjr_t is the job-to-job transition rate. We compute the “alternative” history in which the path of productivity is initially hit by a further positive or negative shock in the initial period: i.e. $\{\tilde{a}_t\}_{t=0}^T$ such that $\tilde{a}_0 = a_0 + \sigma$ or $\tilde{a}_0 = a_0 - \sigma$. The corresponding variables under the alternative aggregate productivity path are $\{\tilde{u}_t, e_t(\tilde{x}), \tilde{sr}_t, \tilde{jfr}_t, \tilde{jjr}_t\}_{t=0}^T$. Because the value of \tilde{a}_t does not fall on one of the nodes of the discretized grid, we compute the paths of all variables using a linear interpolation of the policy functions. After taking quarterly averages, the IRF for a given variable is computed as the difference between the values under the alternative and the baseline history: e.g. $du_q = \tilde{u}_q - u_q$ for the unemployment response, where q represents a one-quarter period. The 10th, 50th, and 90th percentile IRFs are calculated as the relevant percentiles of du_t (or any other variable) across all simulations at each $t = 0, T$.⁴²

G Model with layoff taxes: additional details

The measure of employed workers with individual productivity below x has the following law of motion. For those workers whose individual productivity is in the OJS

⁴¹We start with an initial 200 observations that are then discarded.

⁴²It is important to note that the plotted IRFs therefore do not represent a specific and unique response, but simply the percentiles of the distribution of responses in period t .

interval $[x_t^{r,O}, x_t^s]$:

$$\begin{aligned}
e_{t+1}(x) = & p(\theta_t)(1 - e_t(x_H))(F(x) - F[x_{t+1}^{r,N}]) + p(\theta_t)(F(x) - F[x_{t+1}^{r,N}])e_t(x_t^s) \\
& + (1 - s) \left[\lambda(F(x) - F[x_{t+1}^{r,O}]) \left(e_t(x_H) - p(\theta_t)(1 - F[x_{t+1}^{r,N}])e_t(x_t^s) \right) \right. \\
& \left. + (1 - \lambda) \left(e_t(x) - e_t(x_{t+1}^{r,O}) \right) \left(1 - p(\theta_t)(1 - F[x_{t+1}^{r,N}]) \right) \right].
\end{aligned}$$

For the non-searching workers, with $x > x_t^s$:

$$\begin{aligned}
e_{t+1}(x) = & p(\theta_t)(1 - e_t(x_H))(F(x) - F[x_{t+1}^{r,N}]) + p(\theta_t)(F(x) - F[x_{t+1}^{r,N}])e_t(x_t^s) \\
& + (1 - s) \left[\lambda(F(x) - F[x_{t+1}^{r,O}]) \left(e_t(x_H) - p(\theta_t)(1 - F[x_{t+1}^{r,N}])e_t(x_t^s) \right) \right. \\
& \left. + (1 - \lambda) \left(e_t(x) - e_t(x_t^s) + (1 - p(\theta_t)(1 - F[x_{t+1}^{r,N}]))(e_t(x_t^s) - e_t(x_{t+1}^{r,O})) \right) \right].
\end{aligned}$$

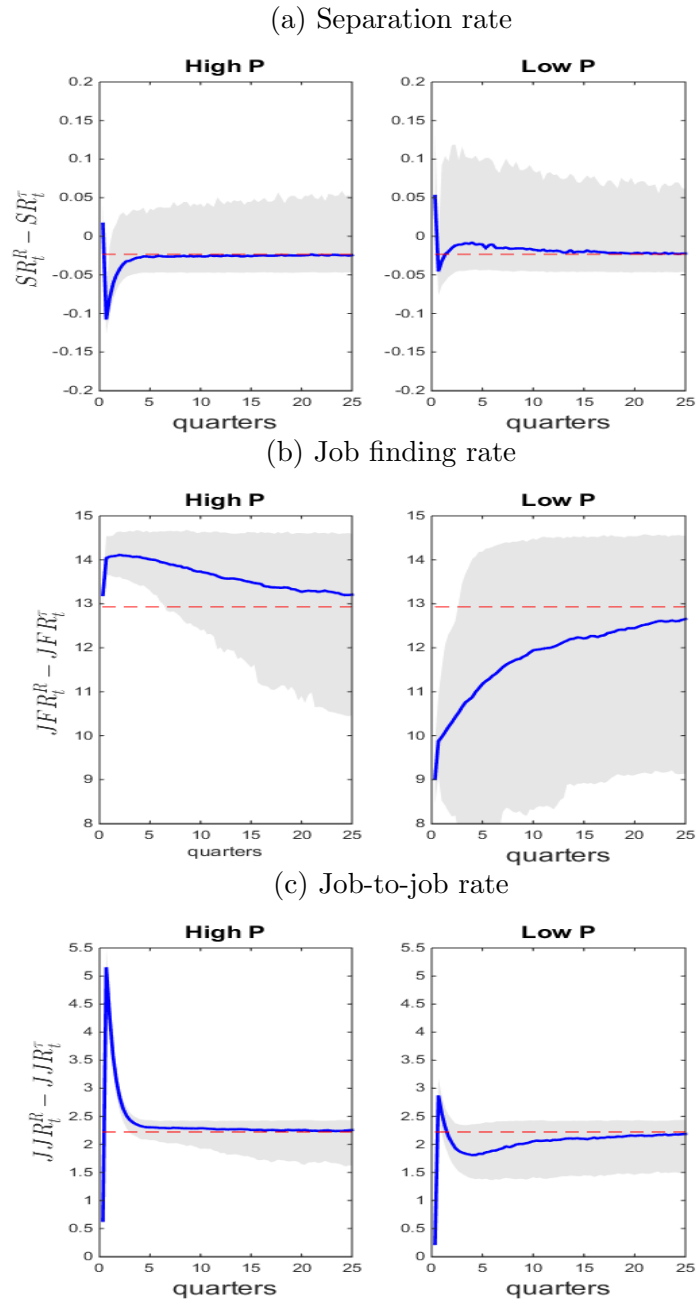
H Simulation of the layoff tax removal

We use a long simulation of the model economy with the tax in place to obtain a distribution of state variables $\{e_{t-1}(x), a_t\}$ when labor productivity is at the 10th and 90th percentiles, representing the trough and peak of the productivity cycle. From these distributions we draw (with replacement) a sample of 2,000 initial starting points. For each starting point we simulate the ensuing path of aggregate productivity through a random sequence of exogenous innovations for 25 quarters (75 months). For each sampled technology series we then compute the path of the economy under two scenarios. In the first scenario there are no changes to the economy, and the tax is expected to remain in place forever. In the second scenario there is an unannounced permanent elimination of the tax in period 0.⁴³ This alternative scenario is interpreted as the “structural reform” case.

⁴³Specifically, in the first case the path of the economy is computed using the firms’ policy function for the model with tax, while in the second case the policy function used from period 0 onward is the solution for the baseline model without the tax.

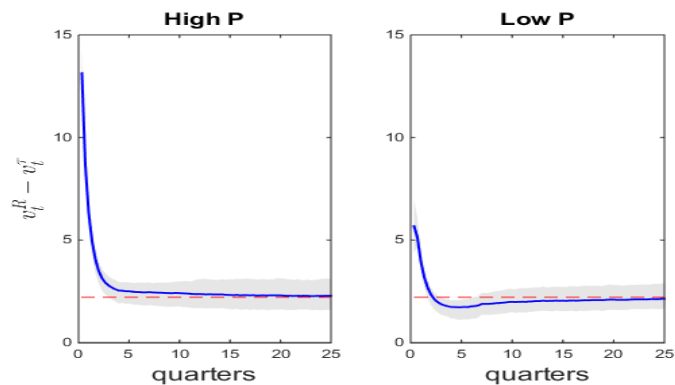
I Transition path of labor market variables

Figure I.1: Transition path of the separation rate, job finding rate, and job-to-job rate to a permanent elimination of the layoff tax.



Notes: The solid blue lines represent the average difference in the respective variable for the economy where at time 0 the layoff tax was abolished from that of the same economy where the tax persists from 2,000 simulations of the model. The shaded grey area represents the 10th-90th percentile interval of the differences. The dashed red line represents the long-run average difference between the two economies.

Figure I.2: Transition path of aggregate vacancies to a permanent elimination of the layoff tax.



Notes: The solid blue line represents the average difference in aggregate vacancies rate of the economy where at time 0 the layoff tax was abolished from that of the same economy where the tax persists from 2,000 simulations of the model. The shaded grey area represents the 10th-90th percentile interval of the differences. The dashed red line represents the long-run average difference between the two economies.

J Robustness checks, variance of labor market variables

Table J.1: Robustness of the variables' standard deviation to different time samples, to an HP-weight of 10^5 , and to using the TFP series by John Fernald as the productivity variable.

	p < 50 th percentile	Baseline p > 50 th percentile	$\sigma_{<50}/\sigma_{>50}$	Pre Great Recession p < 50 th percentile	Pre Great Recession p > 50 th percentile	$\sigma_{<50}/\sigma_{>50}$	Great Moderation p < 50 th percentile	Great Moderation p > 50 th percentile	$\sigma_{<50}/\sigma_{>50}$
Levels									
Unemployment	0.1465	0.1194	1.23	0.1471	0.1164	1.26	0.1180	0.0947	1.25
Job Finding Rate	0.0371	0.0345	1.07	0.0375	0.0343	1.09	0.0315	0.0298	1.06
Separation Rate	0.0021	0.0013	1.57	0.0021	0.0014	1.52	0.0018	0.0011	1.67
Employment Rate	0.0095	0.0072	1.32	0.0092	0.0066	1.40	0.0088	0.0061	1.44
Output	0.0221	0.0165	1.34	0.0222	0.0165	1.34	0.0218	0.0115	1.90
Productivity	0.0119	0.0095	1.26	0.0122	0.0096	1.26	0.0105	0.0071	1.48
Growth rates									
Unemployment	0.0829	0.0401	2.06	0.0833	0.0415	2.01	0.0476	0.0308	1.54
Job Finding Rate	0.0240	0.0192	1.25	0.0242	0.0196	1.23	0.0169	0.0156	1.08
Separation Rate	0.0576	0.0497	1.16	0.0020	0.0016	1.25	0.0017	0.0013	1.34
Employment Rate	0.0051	0.0023	2.15	0.0049	0.0024	2.06	0.0034	0.0024	1.44
Output	0.0153	0.0090	1.71	0.0153	0.0091	1.69	0.0112	0.0068	1.64
Productivity	0.0099	0.0074	1.34	0.0100	0.0075	1.34	0.0083	0.0059	1.42

	HP weight 10^5			25 th – 75 th Cutoffs			TFP series by John Fernald		
	p < 50 th percentile	p > 50 th percentile	$\sigma_{<50}/\sigma_{>50}$	p < 50 th percentile	p > 50 th percentile	$\sigma_{<50}/\sigma_{>50}$	p < 50 th percentile	p > 50 th percentile	$\sigma_{<50}/\sigma_{>50}$
Level									
Unemployment	0.139	0.130	1.07	0.148	0.120	1.23	0.139	0.13	1.07
Job Finding Rate	0.036	0.037	0.97	0.035	0.034	1.02	0.036	0.04	0.97
Separation Rate	0.002	0.001	1.53	0.002	0.001	1.58	0.002	0.00	1.53
Employment Rate	0.009	0.008	1.19	0.010	0.007	1.37	0.009	0.01	1.19
Output	0.022	0.018	1.26	0.021	0.018	1.16	0.022	0.02	1.26
Productivity	0.012	0.010	1.24	0.012	0.010	1.23	0.012	0.01	1.25
Growth rate									
Unemployment	0.085	0.040	2.10	0.090	0.037	2.46	0.085	0.04	2.10
Job Finding Rate	0.025	0.019	1.31	0.023	0.018	1.24	0.025	0.02	1.31
Separation Rate	0.002	0.001	1.32	0.002	0.002	1.30	0.002	0.00	1.32
Employment Rate	0.005	0.002	2.41	0.006	0.002	2.35	0.005	0.00	2.41
Output	0.015	0.009	1.72	0.017	0.010	1.74	0.015	0.01	1.72
Productivity	0.010	0.008	1.30	0.010	0.008	1.28	0.010	0.01	1.35

K Robustness checks, regression analysis

Table K.1: Robustness of the results in Table 2 to the pre-Great Recession and the Great Moderation sub-samples (columns 1-2 and 4-5), to using an HP-filter weight of 10^5 (columns 3 and 7), and to using the TFP series by John Fernald as the productivity variable (columns 4 and 8). Dependent variables: log of unemployment rate and job finding rate.

	Unemployment				JFR			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
log p_t	-4.781*** (0.631)	-3.916*** (0.546)	-3.553*** (0.618)	-5.197*** (0.631)	0.838*** (0.242)	0.618** (0.251)	0.865*** (0.259)	1.172*** (0.239)
High p_t	0.012 (0.010)	0.017* (0.009)	-0.000 (0.013)	0.006 (0.009)	-0.001 (0.004)	-0.003 (0.004)	-0.003 (0.005)	0.000 (0.003)
log p_t * High p_t	2.622*** (0.963)	2.371*** (0.838)	2.302** (0.947)	3.010*** (0.953)	-0.693* (0.378)	-0.251 (0.388)	-0.659* (0.392)	-1.384*** (0.369)
log p_{t-1}	-0.057 (0.684)	-0.281 (0.584)	1.465** (0.647)	0.179 (0.664)	0.350 (0.262)	0.396 (0.266)	-0.357 (0.270)	0.199 (0.252)
High p_{t-1}	-0.005 (0.010)	0.000 (0.009)	0.003 (0.013)	0.008 (0.009)	0.002 (0.004)	0.003 (0.004)	0.003 (0.005)	-0.007* (0.003)
log p_{t-1} * High p_{t-1}	0.924 (0.981)	0.435 (0.847)	-1.245 (0.950)	-0.081 (0.958)	-0.118 (0.383)	-0.446 (0.391)	0.640 (0.394)	0.878** (0.371)
Lagged Dependent	0.874*** (0.026)	0.908*** (0.024)	0.925*** (0.020)	0.829*** (0.025)	0.761*** (0.037)	0.837*** (0.039)	1.003*** (0.046)	0.716*** (0.035)
Constant	-0.023*** (0.008)	-0.023*** (0.006)	-0.013 (0.009)	-0.023*** (0.007)	0.004 (0.003)	0.004 (0.003)	0.001 (0.004)	0.006** (0.003)
Observations	231	152	259	259	231	152	259	259
R-squared	0.883	0.935	0.918	0.894	0.759	0.831	0.726	0.782
Sample	1950-2007	1980-2007	1950-2014	1950-2014	1950-2007	1980-2007	1950-2014	1950-2014
HP-filter	1600	1600	10^5	1600	1600	1600	10^5	1600
Productivity Series	ALP	ALP	ALP	Fern.	ALP	ALP	ALP	Fern.

Standard errors in parentheses

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table K.2: Robustness of the results in Table 2 to the pre-Great Recession and the Great Moderation sub-samples (columns 9-10 and 13-14), to using an HP-filter weight of 10^5 (columns 11 and 15), and to using the TFP series by John Fernald (columns 12 and 16) as the productivity variable. Dependent variables: separation rate and log of employment rate.

	SR				Employment			
	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
log p_t	-0.119*** (0.018)	-0.139*** (0.020)	-0.081*** (0.016)	-0.131*** (0.018)	0.288*** (0.035)	0.274*** (0.039)	0.226*** (0.037)	0.335*** (0.036)
High p_t	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	0.000 (0.000)	-0.001* (0.001)	-0.001** (0.001)	-0.000 (0.001)	-0.001 (0.001)
log p_t * High p_t	0.105*** (0.029)	0.149*** (0.031)	0.080*** (0.024)	0.072** (0.029)	-0.161*** (0.053)	-0.176*** (0.059)	-0.162*** (0.057)	-0.223*** (0.054)
log p_{t-1}	0.028 (0.020)	0.021 (0.021)	0.047*** (0.016)	0.046** (0.019)	0.060 (0.038)	0.042 (0.042)	-0.061 (0.039)	0.028 (0.038)
High p_{t-1}	-0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.001)	-0.000 (0.001)	-0.000 (0.001)	-0.001 (0.001)
log p_{t-1} * High p_{t-1}	-0.033 (0.030)	-0.080** (0.032)	-0.060** (0.025)	-0.022 (0.029)	-0.104* (0.054)	-0.049 (0.060)	0.042 (0.057)	-0.028 (0.054)
Lagged Dependent	0.348*** (0.063)	0.233*** (0.075)	0.505*** (0.057)	0.313*** (0.061)	0.862*** (0.025)	0.893*** (0.025)	0.932*** (0.020)	0.828*** (0.023)
Constant	-0.000* (0.000)	-0.001*** (0.000)	-0.000 (0.000)	-0.000 (0.000)	0.002*** (0.000)	0.002*** (0.000)	0.001*** (0.001)	0.002*** (0.000)
Observations	231	152	259	259	231	152	259	259
R-squared	0.459	0.536	0.451	0.484	0.904	0.933	0.926	0.914
Sample	1950-2007	1980-2007	1950-2014	1950-2014	1950-2007	1980-2007	1950-2014	1950-2014
HP-filter	1600	1600	10^5	1600	1600	1600	10^5	1600
Productivity Series	ALP	ALP	ALP	Fern.	ALP	ALP	ALP	Fern.

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

L Robustness checks, skewness

Table L.1: Robustness of the variables' skewness to different time samples and to using an HP-weight of 10^5 .

	Baseline		Pre Great Recession		Great Moderation		HP weight 10^5
	Level	Growth Rate	Level	Growth Rate	Level	Growth Rate	Level
Unemployment	0.402	1.386	0.452	1.401	0.099	0.918	0.113
Job Finding Rate	-0.293	-0.385	-0.337	-0.391	-0.199	-0.042	-0.202
Separation Rate	0.772	0.478	0.747	0.475	0.780	0.289	0.727
Employment Rate	-0.666	-1.214	-0.724	-1.143	-0.762	-0.660	-0.668
Output	-0.509	-0.098	-0.531	-0.037	-1.074	-0.859	-0.326
Productivity	-0.363	0.070	-0.366	0.076	-0.872	-0.261	-0.291

Table L.2: Simulated skewness of monthly growth rates in the model.

	Average Skewness
Unemployment	0.855
Job Findin Rate	-0.063
Separation Rate	0.573
Employment Rate	-0.998
Output	-0.193
Productivity	0.067