The Scarring Effect of Asymmetric Business Cycles*

Domenico Ferraro   Giuseppe Fiori

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Abstract

We formulate an equilibrium model of the business cycle featuring search frictions and a labor supply decision along the extensive margin, that reconciles the cyclical asymmetry in the U.S. unemployment rate with the symmetric fluctuations of the participation rate. We discipline the model parameters using observations on gross worker flows across the three labor market states: employment, unemployment, and nonparticipation. The model predicts that the U.S. employment-to-population ratio would be 0.3 percentage points higher (or, equivalently, a gain of about a million jobs) in the absence of business cycles. We name this phenomenon the "scarring effect" of the asymmetric business cycle. By reducing the depth of recessions, countercyclical stabilization policy leads to permanent gains in the average level of employment and output.

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*Ferraro: Department of Economics, W.P. Carey School of Business, Arizona State University, PO Box 879801, Tempe, AZ 85287-9801, United States (e-mail: domenico.ferraro@asu.edu); Fiori: Department of Economics, Poole College of Management, North Carolina State University, Campus Box 8110, Raleigh, NC 27695-8110, United States (e-mail: gfiori@ncsu.edu). First version: February 12, 2018. We thank Steven Davis, Maximiliano Dvorkin, Jan Eeckhout, Nezih Guner, Kyle Herkenhoff, Cosmin Ilut, David Lagakos, Kurt Mitman, Giuseppe Moscarini, Toshihiko Mukoyama, José-Víctor Ríos-Rull, Richard Rogerson, Raül Santaeulàlia-Llopis, Nora Traum, Ludo Visschers, and seminar participants at 2018 Economic Growth and Fluctuations Barcelona GSE Summer Forum, 2018 Annual Meeting of the Society for Economic Dynamics (SED), 2018 Annual Meeting of the European Economic Association (EEA), 2018 Computing in Economics and Finance (CEF) for valuable comments and discussions.

1 Introduction

The employment-to-population ratio in the United States displays a marked asymmetry: deviations below trend (troughs) are larger than deviations above trend (peaks), which generates significant negative skewness in the distribution of aggregate labor and output in deviations from trend (see, e.g., Sichel, 1993; McKay and Reis, 2008). In Section 2, we show that this asymmetry is accounted for solely by the behavior of the unemployment rate, which displays positive skewness in deviations from trend. By contrast, cyclical fluctuations in the labor force participation rate are virtually symmetric around trend.

These empirical observations are puzzling. Standard theory predicts unemployment and participation rates to be jointly determined as an equilibrium outcome, based on the opportunity cost of employment, i.e. the return of market to nonmarket work. And that, as a result, cyclical shocks that affect unemployment are likely to affect participation as well. In this sense, the marked asymmetry in the U.S. unemployment rate and the lack thereof in the participation rate raise the question of what are the economic mechanisms responsible for this disconnect.

To answer this question, we build an equilibrium model of the aggregate labor market, in which the nonlinear propagation mechanism of cyclical shocks *endogenously* shapes the distribution of aggregate outcomes. The model features search frictions and a labor force participation decision, generating gross worker flows across the three labor market states: employment, unemployment, and nonparticipation. We parametrize the model to reproduce averages, cyclical volatilities, and comovement of U.S. gross worker flows and find that it accounts for the asymmetry in the employment-to-population ratio, as well as producing positive skewness in the unemployment rate and the lack thereof in the participation rate as in the data. Generating these patterns is the first contribution of the paper.

The main lesson from our quantitative experiments is that the asymmetric response of the economy to cyclical shocks has a "scarring effect," which reduces the average *level* of the employment-to-population ratio around which the economy fluctuates. Moreover, the larger the volatility of cyclical shocks, the larger the implied reduction in employment. To quantify this job loss, we use our model and find that the scarring effect reduces the average employment-to-population ratio by 0.3 percentage points (or, equivalently, a loss of about a million jobs). We then conclude that countercyclical stabilization policy has benefits that go beyond reducing the volatility of fluctuations. By reducing the depth of recessions, it increases the average level of employment, which raises welfare regardless of the individuals' aversion towards risk. In our model, a simple rule that allows the income tax rate to move procyclically reduces the estimated job loss by 70%. Quantifying these effects is the second contribution of the paper.

Our results challenge a long-standing tradition in business cycle research that studies linearized or close-to-linear models. In that tradition, cyclical fluctuations are viewed as symmetric around the trend and stabilization policies can smooth the business cycle but are inconsequential for the average level of economic activity. However, the presence of negative skewness in labor and output at the macro level and recent evidence at the micro level calls into question this approach (see Ilut, Kehrig and Schneider, 2017; Berger and Vavra, 2018). While one might argue that the presence of skewness is a phenomenon of interest per se, here we stress that skewness and more so the disconnect between the asymmetry properties of unemployment and participation rates provide overidentifying restrictions that greatly discipline our quantitative experiments.

In Section 3, we present our model economy. The main idea is that hiring is subject to search frictions and individual participation decisions are described by occasionally-binding constraints (akin to individual labor supply decisions with indivisible labor). In principle, search frictions and participation decisions, and their interactions, can induce a high degree of curvature in the equilibrium relationship between aggregate employment and the shocks hitting the economy. Notably, whether this relation is convex or concave, and whether the degree of curvature is quantitatively important, critically depends on the parameterization of the model. Through the lens of our calibrated economy, we find that the equilibrium displays a *concave* relationship between employment and the cyclical shocks. Intuitively, this concave relationship implies that the economy responds more to bad shocks than to good shocks: bad shocks lead to deep recessions, good shocks lead to meek expansions. We thus obtain negative skewness in the time series even though aggregate shocks are not skewed.

To explain the source of this nonlinearity, it is useful to describe the structure of the model in more detail. There are two types of agents: individuals and employers. In the spirit of Becker (1965), individuals solve a time allocation problem. They are endowed with one unit time that can be allocated to three uses: market work, job search, and non-market work (e.g. leisure and/or home production). Market work and job search entail a utility cost modeled as the share of the value of nonmarket work that the individual forgoes when working or searching. Individuals are heterogeneous in their valuation (or, equivalently, productivity) of nonmarket work which yields an extensive margin of employment determination. Employers post job vacancies at a cost to hire individuals. Production requires the creation of a match between an individual and an employer (a "job," hereafter). (Wages are fully flexible and determined via period-by-period bilateral Nash-bargaining.)

The model has three key ingredients. First, search frictions prevent the instantaneous matching of individuals seeking jobs with employers. As a result, unemployment arises as an equilibrium outcome (see Pissarides, 1985; Mortensen and Pissarides, 1994). In the Mortensen-Pissarides model, individuals always want to work but due to frictions and idiosyncratic shocks to the viability of a job, they occasionally flow between employment and unemployment. Second, individuals are subject to idiosyncratic preference shocks to the value of nonmarket work, which drives participation decisions and thereby flows between employment and nonemployment (see Benhabib, Rogerson and Wright, 1991). Altogether, the stochastic steady state of the model features endogenous flows between employment, unemployment, and nonparticipation. Third, the economy features both idiosyncratic and aggregate risk. We introduce idiosyncratic risk in the form of cyclicality in the probability of receiving a preference shock and in the probability of job destruction. These shocks are reallocative in the sense that they increase the cross-sectional dispersion of labor market outcomes. Aggregate risk takes the form of temporary and persistent variations in the productivity of a job, a technology shock. A positive technology shock increases the profitability of job creation, thus boosting vacancy posting and individuals' entry in the labor force.

Given these ingredients, the model features two transmission mechanisms through which symmetric cyclical shocks can induce asymmetry in aggregate outcomes: (i) endogenous fluctuations in the level of frictions; and (ii) individual participation decisions. In equilibrium, these two mechanisms naturally interact with each other.

First, to capture frictions, we follow the literature and assume a constant returns-to-scale (CRS) meeting technology, which expresses meetings as function of job seekers and vacancies (see Petrongolo and Pissarides, 2001). Diminishing returns to the inputs of the meeting technology imply that the probability that a job seeker meets a vacancy is concave in market tightness—the ratio of job vacancies to job seekers—which captures aggregate congestion effects due to random search. Due to this concavity, the job seeker probability of meeting a vacancy falls more in response to a drop in tightness than it raises in response to an equally-sized increase. Conversely, the probability that a vacancy meets a job seeker is convex in the tightness ratio, which induces downward rigidity in hiring costs as an equilibrium outcome. Expansions are periods in which many job vacancies compete for a relatively small pool of job seekers, so that the posting of an additional job vacancy can cause a large drop in the probability that a given vacancy meets a job seeker. As a result, during expansions, hiring costs increase sharply. Recessions are periods in which many job seekers compete for a small pool of vacancies. Due to congestion effects, an additional vacancy has a small impact on the already high probability that a vacancy meets a job seeker. As a result, during recessions, hiring costs decrease smoothly. Whether the degree of convexity in hiring costs is quantitatively important critically depends on the model's ability to generate empirically plausible fluctuations in the equilibrium market tightness ratio. As in Gavazza, Mongey and Violante (2018), we call this transmission mechanism the *slackness effect*, in reference to aggregate-level conditions determining the speed at which vacancies meet job seekers.

Second, when individuals make participation decisions, they face a trade-off between the expected return of entering the labor force and the forgone value of nonmarket work. The participation decision follows a reservation policy: if the productivity of nonmarket work is above a cutoff value, the individual is out of the labor force, otherwise she/he is in the labor force. We interpret individual participation decisions as optimal labor supply responses to changes in the environment. Here, we stress that the lack of asymmetry in the aggregate participation rate is not hard-wired into the model. The indivisibility of the individual labor supply decisions may or may not generate asymmetry in the aggregate participation rate depending on the aggregation over individuals with different values of nonmarket work. We call this second transmission mechanism the *labor supply effect*.

In Section 4 and 5, we take the model to the data and evaluate its implications. Our examination of the transmission mechanism indicates that: (i) the slackness effect is the dominant force behind the asymmetry in the unemployment rate, whereas (ii) the labor supply effect accounts for virtually the entirety of the volatility and the lack of asymmetry in the labor force participation rate. Further, (iii) we stress that in the model the labor supply effect accounts for nearly *one-third* of the volatility of the unemployment rate, which lines up nicely with the empirical evidence in Elsby, Hobijn and Şahin (2015).

In the model, the extent of asymmetry in the unemployment and participation rates depends on the relative strength of competing forces that determine gross worker flows between the three states of the labor market. In this regard, counterfactual experiments deliver two important insights. First, quantitatively, we find that key to explaining the cyclical asymmetry in the unemployment rate is the cyclical behavior of the job-finding rate, which reflects nonlinearities inherent to the search process.

Second, the lack of asymmetry in the participation rate reflects two competing forces that offset each other. On the one hand, the participation rate inherits the asymmetry of the job-finding rate; other things equal, it drops more below trend in contractions than it raises above trend in expansions. This pattern would lead to a counterfactually negative skewness in the participation rate. One the other hand, participation decisions alone would lead to a counterfactually positive skewness in the participation rate. Which of these two forces dominates critically depends on the mass of individuals at the margin between participating and not-participating. To discipline this margin, we restrict the model to match the mean and cyclical volatility of the participation rate. Using U.S. data, this calibration strategy implies that these two forces cancel each other out, leading to symmetric fluctuations in the participation rate.

In Section 6, we use the model to measure the job loss due to the asymmetric business cycle and the benefits of countercyclical tax policy. We find that cyclical fluctuations of the magnitude observed in the post-war period have led to a 0.3 percentage points reduction in the average level of the U.S. employment-to-population ratio. Endogenous fluctuations in the level of frictions are the primary source of this job loss.

Finally, we quantify the effectiveness of income tax rates as a tool of countercyclical stabilization policy. By affecting the effective return to market work, tax rates shape the incentives to post vacancies and to participate in the labor market. Whether tax changes exacerbate or attenuate the scarring effect of fluctuations depends on the extent to which they are correlated with the cycle. By reducing the depth of recessions, countercyclical tax policy reduces the estimated job loss by 70%, leading to a permanent gain in employment. In contrast, erratic tax policy adds to the overall volatility of the economy exacerbating the scarring effect of business cycles. The model produces a *convex* relationship between the income tax rate and the unemployment rate, implying that variability in tax rates increases the average unemployment rate of the economy. This prediction provides an alternative rationale for the tax-smoothing argument formulated in Barro (1979). Section 7 concludes.

1.1 Related literature

Our work is related to several strands of existing literature. One of these is the literature on asymmetric business cycles which dates back to Burns and Mitchell (1946). Though it has been well documented that aggregate labor and output move asymmetrically over the business cycle (see, e.g., Neftçi, 1984; Falk, 1986; Hamilton, 1989; McQueen and Thorley, 1993; Sichel, 1993; McKay and Reis, 2008), surprisingly little quantitative work has been done in the context of equilibrium business cycle models. Arguably, the reason behind this dearth of work lies on the well-known fact that workhorse models of the business cycle fall short of generating quantitatively important nonlinearities. For example, the standard real business cycle (RBC) model produces equilibrium stochastic processes for aggregate labor and output that are approximately linear, generating virtually symmetric fluctuations around the trend (see Kydland and Prescott, 1982; Hansen, 1985).

Hansen and Prescott (2005) was an effort to reproduce the negative skewness in U.S. hours worked within the context of an RBC model with occasionally-binding capacity constraints. Van Nieuwerburgh and Veldkamp (2006) and McKay and Reis (2008) study cyclical asymmetry in an RBC model augmented with learning about technology shocks and asymmetric adjustment costs on employment, respectively. What distinguishes our work is the study of a new set of transmission mechanisms. Also, without frictions, this early work is unable to speak to the observations on unemployment and participation rates, separately, a key observation we aim to explain.

Our work builds on the literature that studies the aggregate implications of three-state models of the labor market. The bulk of this body of work considers steady-state outcomes only (see Garibaldi and Wasmer, 2005; Pries and Rogerson, 2009; Krusell et al., 2008, 2010, 2011). While several attempts have been made to confront these models with the cyclical properties of labor market outcomes, success has been limited (see Tripier, 2004; Veracierto, 2008; Shimer, 2013). Only recently, Krusell et al. (2017) show that a model with idiosyncratic risk, incomplete markets, and labor market frictions can account for the cyclical volatility and comovement of the U.S. gross worker flows. In their setting, job-finding rates are exogenous stochastic processes. By contrast, in our setting, job-finding rates are endogenously determined as an equilibrium outcome, based on the individuals' participation decisions and the free-entry condition for vacancy posting. This property of the equilibrium is instrumental in uncovering frictions as the main source of the scarring effect of business cycles. In addition, as the level of frictions endogenously responds to changes in income tax rates, our experiments on the benefits of stabilization policy are robust to the Lucas (1976)'s critique, that the economy's response to shocks depends on the tax policy *rule* in place.

Our work also relates to the literature based on the Diamond-Mortensen-Pissarides (DMP) model of unemployment (see Diamond, 1982; Mortensen, 1982; Pissarides, 1985).

The bulk of the quantitative work in this literature stresses volatility, comovement, and persistence—what we call standard business cycle moments—as the key phenomena of interest (see, e.g., Merz, 1995; Andolfatto, 1996; Den Haan, Ramey and Watson, 2000; Shimer, 2005; Hall, 2005; Hagedorn and Manovskii, 2008; Pissarides, 2009; Brügemann and Moscarini, 2010; Menzio and Shi, 2011). Here, we articulate the view that higher-order moments, notably skewness, capture important features of the business cycle. And that identifying the determinants of this cyclical skewness deepens our understanding of the mechanisms of fluctuations. In fact, Andolfatto (1997) was an early work to study the asymmetry in the unemployment rate in a search environment. His work stresses the role of asymmetric fluctuations in the job destruction rate. Other work argues that congestion effects from search frictions can lead to nonlinearities in unemployment fluctuations (see Hairault, Langot and Osotimehin, 2010; Jung and Kuester, 2011; Petrosky-Nadeau and Zhang, 2013; Petrosky-Nadeau, Zhang and Kuehn, 2015; Ferraro, 2016, 2017; Petrosky-Nadeau and Zhang, 2017). These papers consider a two-state representation of the labor market which abstracts from the labor force participation decision. Our contribution to this literature is twofold. First, we propose a unified explanation for the asymmetry in the U.S. unemployment rate and the lack thereof in the participation rate. Importantly, our model is consistent with key observations on labor market stocks and gross worker flows as well. Second, we measure the job loss due to the asymmetric business cycle and quantify the effectiveness of countercyclical tax policy in reducing it.

In our view, accounting for the joint dynamics of unemployment, employment, and nonparticipation, in addition to the gross worker flows between the three labor market states, provides a great deal of discipline to our quantitative experiments. Further, as shown by Elsby, Hobijn and Şahin (2015), the participation margin plays a quantitatively important role in unemployment fluctuations. Thus, a three-state representation of the labor market would seem the abstraction that better captures the nature of unemployment fluctuations, let alone the interest in the cyclical properties of the participation rate.

Within the DMP framework, Abbritti and Fahr (2013) and Dupraz, Nakamura and Steinsson (2016) study the implications for cyclical asymmetry of downward nominal wage rigidities.[1] In our model, wages are flexible in the sense that they are determined via period-by-period Nash-bargaining, thus instantaneously responding to the arrival of new information. However, nonlinearities inherent to the matching process induce a degree of downward rigidity in hiring costs, a key determinant of cyclical asymmetry in the model.

[1] See Devereux and Siu (2007) for an equilibrium business cycle model with state-dependent pricing, which generates the observed cyclical asymmetry in aggregate output.

Our results on the benefits of stabilization policy relate to Arseneau and Chugh (2012). In the context of a model with search frictions and endogenous participation, they study optimal tax policy. However, their solution method removes nonlinearities in equilibrium dynamics, by construction, thus abstracting from the scarring effect of fluctuations that is instead the focus of our work. While we do not study optimal policy, our experiments identify a new channel through which procyclical labor tax rates can be beneficial to the extent that they imply a permanent gain in the average level of aggregate employment and output.

Finally, we argue that the model economy presented here can be used as a laboratory to quantitatively evaluate the nonlinearities in the propagation mechanism of fiscal policy, an issue that has received renewed interest in the aftermath of the Great Recession (see, e.g., Auerbach, Gale and Harris, 2010; Parker, 2011; Auerbach and Gorodnichenko, 2012; Ramey and Zubairy, 2014).[2]

2 Facts

In this section, we detail the empirical observations that motivate our work. We study the degree of asymmetry in labor market fluctuations at business cycle frequency. Based on Sichel (1993), we measure cyclical asymmetry with the third standardized central moment or *skewness* of the cyclical component $\hat{x}_t$ of the time series x_t:

$$\text{skew}(\hat{x}_t) = \frac{\mathbb{E}\left[\left(\hat{x}_t - \mathbb{E}\left[\hat{x}_t\right]\right)^3\right]}{\sigma_{\hat{x}}^3},$$

where $\mathbb{E}$ denotes the mathematical expectation operator and $\sigma_{\hat{x}}$ the standard deviation of the cyclical component $\hat{x}_t$ expressed in percent deviations from trend. As customary in the literature, fluctuations at the business cycle frequency are identified as occurring between 2 and 32 quarters. Also, since there is no firm consensus on the filtering approach, we report skewness statistics based on two alternative bandpass methods due to Baxter and King (1999) and Christiano and Fitzgerald (2003), as well as the procedure in Hodrick and Prescott (1997). To test for asymmetry against the null hypothesis of symmetry, we use the test developed by Bai and Ng (2005). (See Appendix A for details on data sources.)

[2] Ouyang (2009) studies the scarring effect of business cycles on productivity, entry and exit dynamics. She finds that recessions impede the developments of potentially superior firms by destroying them during their infancy with permanent negative effects on aggregate productivity.

Skewness Table 1 reports skewness statistics, with associated p-values, for the U.S. employment-to-population ratio, the employment rate (i.e. one minus the unemployment rare), and the labor force participation rate, in the post-war period 1948-2016. To interpret the results, we consider the following decomposition of the employment-to-population ratio:

$$\frac{\text{emp}}{\text{pop}} = \underbrace{\left(1 - \frac{\text{unemp}}{\text{emp+unemp}}\right)}_{\text{employment rate}} \underbrace{\left(\frac{\text{emp+unemp}}{\text{pop}}\right)}_{\text{participation rate}}.$$

This decomposition shows that employment as a fraction of the working-age population equals the employment rate (fraction of employed workers in the labor force, one minus the unemployment rate) times the participation rate (fraction of the population in the labor force). Hence, in an accounting sense, cyclical asymmetry in the employment-to-population ratio may result from either the unemployment or participation rate, or both.

The results in Table 1 establish that cyclical fluctuations in labor force participation are virtually symmetric, which leaves the unemployment rate as key driving force of cyclical asymmetry in the employment-to-population ratio. Specifically, the cyclical component of the employment-to-population ratio displays sizable and significant negative skewness: deviations below trend (troughs) are larger than deviations above trend (peaks).

Notice also that the negative skewness in the employment-to-population ratio remains significant even in the pre-1980 period. Thus, cyclical asymmetry is not driven by the so-called jobless recoveries of the 1990s, 2000s, or the Great Recession of 2007-2009, rather it is a systematic feature of the U.S. labor market over the entire post-war period.

3 Model

In this section, we present the model: environment; individual agents' problems; and decentralized equilibrium. In the model, individuals are classified as participants (either employed or unemployed) and nonparticipants, consistently with the measurement of the Bureau of Labor Statistics (BLS).

3.1 Environment

Time is discrete and continues forever. The economy is inhabited by two types of agents: individuals and employers. Both agents are infinitely lived, risk-neutral, and discount future values at the same rate $\beta \in (0, 1)$. The mass of individuals is normalized to one. An individual is endowed with one unit of time that can be allocated to three uses: market work, job search, and nonmarket work (e.g., leisure and/or home production). Market work and job search are mutually exclusive activities. An employer is either matched with an individual and producing output, or unmatched and posting job vacancies. The mass of employers is determined in free-entry equilibrium.

Preferences An individual enjoys a per-period utility flow of $c_m + c_n$, where c_m and c_n are market and nonmarket consumption, respectively. First, market consumption equals the wage, w, if the individual is employed, the unemployment insurance (UI) benefit, b, if unemployed, and zero if nonparticipant. Second, nonmarket consumption equals $(1-h)x$ if the individual is employed, $(1-a)x$ if unemployed, and x if nonparticipant, where x is the value (or, equivalently, productivity) of nonmarket work, and h and $a \leq h$ parametrize the flow utility costs entailed by market work and job search, respectively.[3]

Idiosyncratic risk There are two sources of idiosyncratic risk. First, individuals are heterogeneous in their valuation of nonmarket work, x. In addition, the value of x may switch over time with probability λ, which evolves stochastically over time. In the latter event, the new value of x for the next period is drawn from a fixed probability distribution function (p.d.f.), $f(x)$, taken to be log-normal with parameters μ_x and σ_x, defined over the bounded support $x \in \left[x^{\min}, x^{\max}\right]$. With probability $1-\lambda$, the idiosyncratic shock x maintains its current value into the next period. Thus, at the individual level, the value of nonmarket work is persistent, but conditional on a switch, the current value of x does not affect its next period realization. Second, an existing match between an employer and an individual is destroyed for exogenous reasons with probability δ, which also evolves stochastically over time. We interpret λ and δ as reallocative (micro) shocks in the sense that they induce cross-sectional dispersion in labor market outcomes (see Mortensen and Pissarides, 1994; Shimer, 2005). (We describe the calibration of these exogenous stochastic processes in Section 4.)

Meeting technology We postulate the existence of a constant returns-to-scale (CRS)

[3] As pointed out by Benhabib, Rogerson and Wright (1991), one can think of x as value of leisure or home production, interchangeably.

meeting function that determines the meetings between employers and individuals, m, as a function of job searchers, s, and job vacancies, v:

$$m = \chi s^{\alpha} v^{1-\alpha}, \tag{1}$$

where $\alpha \in (0,1)$ is the elasticity of meetings with respect to searchers and χ parametrizes the efficiency of the meeting process. The homogeneity of degree one of the meeting function in (1) implies that the probability that a job searcher meets a vacancy, $p(\vartheta)$, and the probability that a job vacancy meets a searcher, $q(\vartheta)$, can be described in terms of the tightness ratio, $\vartheta \equiv v/s$, such that $p(\vartheta) = \chi\vartheta^{1-\alpha}$ and $q(\vartheta) = \chi\vartheta^{-\alpha}$. Hence, the probability that an individual searcher meets a job vacancy is increasing and concave in the tightness ratio. Conversely, the probability that a job vacancy meets an individual searcher is decreasing and convex in the tightness ratio.

In our setting, the pool of job searchers consists of both unemployed individuals and a randomly selected group of nonparticipants. Unemployed individuals are "active" searchers as they incur the utility cost of job search. Nonparticipants that are randomly drawn in the pool of searchers are viewed as "passive" searchers; they do not incur the cost of job search, but with a constant probability ϕ are costlessly selected into the pool of searchers. Active and passive searchers meet a vacancy with the same probability $p(\vartheta)$. Note that our classification of active searchers as unemployed individuals and passive searchers as nonparticipants is consistent with the approach of the BLS (see Jones and Riddell, 1999, for further discussion). By introducing the concept of passive searchers into the model, we allow for worker flows from nonparticipation to employment, that are both large and highly volatile over the business cycle (see Krusell et al., 2017).[4]

Production technology Production requires one employer and one individual. When a job searcher and an employer meet and agree to create a match (or, equivalently, a job), they produce output, y, which evolves stochastically over time according to an AR(1) process in logs:

$$\ln(y') = (1-\rho_y)\ln(\bar{y}) + \rho_y \ln(y) + \sigma_y \epsilon'_y, \tag{2}$$

[4] We acknowledge that, in the data, some of the observed flows from nonparticipation to employment may be due to time aggregation. As labor market data are sampled at the monthly frequency, measured flows from nonparticipation to employment may be due to unmeasured flows from nonparticipation to unemployment and from unemployment to employment insofar as they occur within the month. Here, we follow Krusell et al. (2017) and introduce a constant exogenous probability of becoming a (passive) searcher. Nonetheless, the flows from nonparticipation to employment remain endogenous in the sense that the individuals optimally decide whether to accept a job, or remain out of the labor force, given the realizations of the state variables.

where $\bar{y}$ is the unconditional mean of output, y, and $\epsilon_y \overset{iid}{\sim} \mathcal{N}(0,1)$ are innovations to the (log) output of a job. The parameters ρ_y and σ_y control the persistence and volatility of the innovations, ϵ_y, respectively. Shocks to y raise output in all matches, thus we interpret them as aggregate (macro) shocks.

Government An employee pays labor income taxes based on the flat rate τ, which evolves stochastically over time according to an AR(1) process in logs:

$$\ln(\tau') = (1-\rho_\tau)\ln(\bar{\tau}) + \rho_\tau \ln(\tau) + \sigma_\tau \epsilon'_\tau, \tag{3}$$

where $\bar{\tau}$ is the unconditional mean of the tax rate, τ, and $\epsilon_\tau \overset{iid}{\sim} \mathcal{N}(0,1)$ are innovations to the (log) flat tax rate. The parameters ρ_τ and σ_τ control the persistence and the volatility of the innovations, ϵ_τ, respectively. The government runs a balanced budget on a period-by-period basis and finances outlays with income taxes and lump-sum transfers. Since individuals are risk-neutral, the timing of lump-sum transfers is irrelevant for allocations.

Timing of events Within a period, events unfold as follows. At the beginning of the period, the aggregate (τ, y) and idiosyncratic, x, states are realized. After these events, the period consists of two stages. In the first stage, separations, participation, and search decisions are made simultaneously. In the second stage, output is produced and wages are paid.

In our setting, there is a separation between the time at which a meeting occurs and the formation of a match (or, equivalently, the creation of a job). During the period, job search and vacancy posting jointly determine the meetings between searchers and employers. At the beginning of next period, bilateral Nash-bargaining occurs and if profitable a meeting is converted into a job. This formulation of the recruiting process is consistent with "non-sequential" search, which receives ample empirical support (see Van Ours and Ridder, 1992; Abbring and Van Ours, 1994; Ommeren and Russo, 2014; Davis and de la Parra, 2017).[5]

3.2 Individual agents' problem

We formulate the individual agents' problem in recursive form at the production stage where idiosyncratic and aggregate states have realized and the individual agents' current

[5]See Stigler (1961), Gal, Landsberger and Levykson (1981), Morgan (1983), and Morgan and Manning (1985) for early theoretical work on non-sequential search and Gautier (2002), Wolthoff (2014), and Albrecht, Gautier and Vroman (2006) for recent work on the efficiency of environments with non-sequential search.

decisions of continuing, destroying, or creating a match have been made. To simplify the computation of the equilibrium, we assume that the switching probability of idiosyncratic shocks, x, and the probability of exogenous job separations are perfectly correlated with the output of the job, y. Throughout the paper, we exploit this assumption and keep only y and τ as aggregate state variables. For future reference, note that, in Section 5, we present results for a variant of the model where λ and δ are constant.

Next, to keep notation to a minimum, we collect the aggregate state variables into a vector, $\Omega \equiv (\tau, y)$, and use primes to denote next period variables.

Employer's problem At the beginning of each period, an employer decides whether to remain in the match and produce output or destroy the match and post a job vacancy. At the production stage, then, the value of a filled job is

$$J(x, \Omega) = y - w + \beta \mathbb{E}\Big[(1-\delta')\, \lambda' \int \max\left\{ J(x', \Omega'), V(\Omega') \right\} dF(x') \\ + (1-\delta')\,(1-\lambda') \max\left\{ J(x, \Omega'), V(\Omega') \right\} + \delta' V(\Omega') \Big], \tag{4}$$

where w is the wage payment to the employee determined via bilateral Nash-bargaining, which we describe below, and $\mathbb{E}$ indicates the mathematical expectation with respect to the next period realization of the aggregate state vector, Ω'. The max operator on the right-hand side of (4) captures the employer's decision of whether to continue or destroy the existing match and post a job vacancy, which occurs at the beginning of next period when the new values of the idiosyncratic and aggregate states are realized.

The value of a posted job vacancy is

$$V(\Omega) = -k + \beta \mathbb{E}\Big[q\,(1-\delta')\, \lambda' \int \max\left\{ J(x', \Omega'), V(\Omega') \right\} dF(x') \\ + q\,(1-\delta')\,(1-\lambda') \int \max\left\{ J(x, \Omega'), V(\Omega') \right\} dG(x) + \left(1 - q\,(1-\delta')\right) V(\Omega') \Big], \tag{5}$$

where k is the per-period unit cost of opening and maintaining a job vacancy.[6] The max operator on the right-hand side of (5) captures the employer's decision of whether to create a match or continue the search process and post a job vacancy at the beginning of next period. Note that the c.d.f. $G(x)$ in (5) accounts for the selection into the pool of job

[6]Note that, as in the textbook Mortensen-Pissarides model, the value of a posted vacancy depends on the aggregate states only (see, e.g., Pissarides, 1985; Mortensen and Pissarides, 1994). In our setting, this property holds as the vacancy cost, k, does not depend on the realization of the idiosyncratic shock, x.

searchers (akin to an inverse Mills ratio), with probability density

$$g(x) \equiv \begin{cases} f(x)/\left\{F(x^v) + \phi\left[F(x^q) - F(x^v)\right]\right\} & \text{for } \; x < x^v \\ \phi f(x)/\left\{F(x^v) + \phi\left[F(x^q) - F(x^v)\right]\right\} & \text{for } \; x^v \le x < x^q \\ 0 & \text{for } \; x \ge x^q, \end{cases} \tag{6}$$

where $f(x)$ is the probability density of individuals at x, and x^v and x^q are search and separation cutoffs, respectively, whose determination we describe below.

Individual's problem At the beginning of each period, an employee decides whether to remain in the match and receive wages or separate. And conditional on separating, the individual has the option to become either unemployed or nonparticipant, thus dropping out of the labor force. At the production stage, the value of being employed is

$$\begin{aligned} W(x,\Omega) = v^W + \beta\mathbb{E}\Big[& (1-\delta')\,\lambda' \int \max\left\{W(x',\Omega'), U(x',\Omega'), H(x',\Omega')\right\} dF(x') \\ & + (1-\delta')\,(1-\lambda')\max\left\{W(x,\Omega'), U(x,\Omega'), H(x,\Omega')\right\} \\ & + \delta'\lambda' \int \max\left\{U(x',\Omega'), H(x',\Omega')\right\} dF(x') \\ & + \delta'\,(1-\lambda')\max\left\{U(x,\Omega'), H(x,\Omega')\right\}\Big], \end{aligned} \tag{7}$$

where $v^W \equiv (1-h)x + (1-\tau)\,w$ is the per-period return to market work, that consists of the utility flow $(1-h)x$ and the after-tax wage $(1-\tau)w$. The first two max operators on the right-hand side of (7) capture the employee's decision of whether to continue or destroy the existing match at the beginning of next period. And conditional on separating, whether to become unemployed or drop out of the labor force. The last two max operators capture instead the individual's decision to become unemployed or nonparticipant in the event the match is exogenously destroyed.

The value of being unemployed is

$$\begin{aligned} U(x,\Omega) = v^U + \beta\mathbb{E}\Big[& p\,(1-\delta')\,\lambda' \int \max\left\{W(x',\Omega'), U(x',\Omega'), H(x',\Omega')\right\} dF(x') \\ & + p\,(1-\delta')\,(1-\lambda')\max\left\{W(x,\Omega'), U(x,\Omega'), H(x,\Omega')\right\} \\ & + (1-p\,(1-\delta'))\,\lambda' \int \max\left\{U(x',\Omega'), H(x',\Omega')\right\} dF(x') \\ & + (1-p\,(1-\delta'))\,(1-\lambda')\max\left\{U(x,\Omega'), H(x,\Omega')\right\}\Big], \end{aligned} \tag{8}$$

where $v^U \equiv (1-a)x + b$ is the per-period return to job search, that consists of the utility flow, $(1-a)x$, and UI benefit, b. The first two max operators on the right-hand side of (8) capture the individual's decision of whether to create a match or stay idle, at the beginning of next period. If the individual decides not to create a match, then she or he has to decide between remaining unemployed or dropping out of the labor force. The last two max operators in (8) capture instead the individual's decision to remain unemployed or drop out of the labor force in the event that either she or he does not meet an employer, or a meeting is exogenously destroyed.

The value of being nonparticipant is

$$\begin{aligned} H(x,\Omega) = x + \beta\mathbb{E}\Big[&\phi p\left(1-\delta'\right)\lambda' \int \max\left\{W(x',\Omega'), U(x',\Omega'), H(x',\Omega')\right\} dF(x') \\ &+ \phi p\left(1-\delta'\right)\left(1-\lambda'\right) \max\left\{W(x,\Omega'), U(x,\Omega'), H(x,\Omega')\right\} \\ &+ \phi\left(1-p\left(1-\delta'\right)\right)\lambda' \int \max\left\{U(x',\Omega'), H(x',\Omega')\right\} dF(x') \\ &+ \phi\left(1-p\left(1-\delta'\right)\right)\left(1-\lambda'\right) \max\left\{U(x,\Omega'), H(x,\Omega')\right\} \\ &+ \left(1-\phi\right)\lambda' \int H(x',\Omega') dF(x') + \left(1-\phi\right)\left(1-\lambda'\right) H(x,\Omega')\Big], \end{aligned} \tag{9}$$

where the value of nonmarket work, x, is the per-period return to nonparticipation. The first two max operators on the right-hand side of (9) capture the passive searcher's choice between working and not-working at the beginning of next period. Also, conditional on not-working, the passive searcher has the option to remain out of the labor force or become an active searcher (i.e., unemployed). The last two max operators in (9) capture instead the passive searcher's decision to become an active searcher or remain out of the labor force in the event that either he or she does not meet a job vacancy, or a meeting is exogenously destroyed. Finally, the last term in (9) describes the event that the individual does not get a chance to meet a vacancy, which occurs with probability $1-\phi$.

Wage determination The wage is determined via bilateral Nash-bargaining. Note that bargaining resumes every period such that currently and newly employed receive the same wage. To form the match, the individual forgoes $\max\{U(x,\Omega), H(x,\Omega)\}$ for $W(x,\Omega)$, whereas the employer forgoes $V(\Omega)$ for $J(x,\Omega)$. The wage derived from Nash-bargaining maximizes the weighted product of individual's and employer's net surplus:

$$w = \arg\max S_w(x,\Omega)^{\eta} \times S_e(x,\Omega)^{1-\eta}, \tag{10}$$

where $S_w(x,\Omega) \equiv W(x,\Omega) - \max\{U(x,\Omega), H(x,\Omega)\}$ and $S_e(x,\Omega) \equiv J(x,\Omega) - V(\Omega)$ denote individual's and employer's net surplus, respectively, and η is the individual's bargaining weight.

The Nash-bargaining problem in (10) yields the tax-adjusted sharing rule,

$$\tilde{\eta} S_e(x,\Omega) = (1-\tilde{\eta})\, S_w(x,\Omega), \text{ with } \tilde{\eta} \equiv \frac{\eta\,(1-\tau)}{\eta\,(1-\tau) + (1-\eta)}, \tag{11}$$

where $\tilde{\eta}$ represents the *effective* bargaining weight.[7] In the spirit of Arseneau and Chugh (2008), we interpret this potentially time-varying wedge as dynamic bargaining power; an increase in the tax rate reduces the effective bargaining power of the individual. Also, the sharing rule in (11) gives employer's and individual's net surplus as proportional to each other, such that $S_w(x,\Omega) = \tilde{\eta} S(x,\Omega)$ and $S_e(x,\Omega) = (1-\tilde{\eta}) S(x,\Omega)$, where $S(x,\Omega) \equiv S_w(x,\Omega) + S_e(x,\Omega)$ denotes the total surplus generated by the match. This property allows us to conveniently work with the equations that describe total match surplus, rather than with the pairs of separate functional equations for the individual and employer.

Total match surplus In our setting, the total match surplus depends on the threat point of the individual in the bargaining. Specifically, if $\max\{U(x,\Omega), H(x,\Omega)\} = U(x,\Omega)$, we view individuals as "attached" to the labor force in the sense that they would prefer to be unemployed than out-of-the-labor-force. If, instead, $\max\{U(x,\Omega), H(x,\Omega)\} = H(x,\Omega)$, we view individuals as "marginally attached" to the labor force in the sense that they would be willing to work, but not actively searching for a job.

At the beginning of each period, an employer and an individual bargain over the wage and they jointly decide whether to continue, destroy, or create a match. At the production stage, the total surplus generated by a match with an *attached* individual is

$$\begin{aligned} S(x,\Omega) = y - [(h-a)x + b + \tau w] + \beta \mathbb{E}\Big[& (1-\delta')\,(1-p\tilde{\eta}')\,\lambda' \int S(x',\Omega')^{+} dF(x') \\ & + (1-\delta')\,(1-p\tilde{\eta}')\,(1-\lambda')\,S(x,\Omega')^{+} \Big], \end{aligned} \tag{12}$$

where $S(\cdot\,,\Omega')^{+} \equiv \max\{S(\cdot\,,\Omega'), 0\}$ on the right-hand side of (12) captures employer's and individual's joint decision of either continuing or destroying the existing match based

[7] Note that the presence of a positive labor tax rate modifies the Hosios (1990)'s condition for efficiency. See Hagedorn and Manovskii (2008) for a discussion.

on the next period aggregate and idiosyncratic states, and the wage paid to the attached individual in (12) is

$$w = \eta y + (1-\eta)\left[\frac{(h-a)x+b}{1-\tau}\right] + \eta\beta\mathbb{E}\Big\{ (1-\delta')\,(1-\tilde{\eta}')\Big[\lambda'\int S(x',\Omega')^{+}dF(x') + (1-\lambda')\,S(x,\Omega')^{+}\Big]\Big\} - \frac{(1-\eta)}{(1-\tau)}\beta\mathbb{E}\Big\{ (1-p)\,(1-\delta')\,\tilde{\eta}'\Big[\lambda'\int S(x',\Omega')^{+}dF(x') + (1-\lambda')\,S(x,\Omega')^{+}\Big]\Big\}. \tag{13}$$

The total surplus generated by a match with a *marginally attached* individual is

$$S(x,\Omega) = y - (hx+\tau w) + \beta\mathbb{E}\Big[(1-\delta')\,(1-\phi p\tilde{\eta}')\,\lambda'\int S(x',\Omega')^{+}dF(x') + (1-\delta')\,(1-\phi p\tilde{\eta}')\,(1-\lambda')\,S(x,\Omega')^{+}\Big], \tag{14}$$

where the wage paid to the marginally attached individual in (14) is

$$w = \eta y + (1-\eta)\left(\frac{hx+b}{1-\tau}\right) + \eta\beta\mathbb{E}\Big\{ (1-\delta')\,(1-\tilde{\eta}')\Big[\lambda'\int S(x',\Omega')^{+}dF(x') + (1-\lambda')\,S(x,\Omega')^{+}\Big]\Big\} - \frac{(1-\eta)}{(1-\tau)}\beta\mathbb{E}\Big\{ (1-\phi p)\,(1-\delta')\,\tilde{\eta}'\Big[\lambda'\int S(x',\Omega')^{+}dF(x') + (1-\lambda')\,S(x,\Omega')^{+}\Big]\Big\}. \tag{15}$$

Free-entry condition As in Pissarides (1985), and many others thereafter, employers post job vacancies until it is profitable to do so, which yields that the cost of posting a vacancy equals its expected benefit at all times, such that $V(\Omega) = 0$ for any realization of the aggregate state vector. As a result, market tightness, ϑ, is determined according to a forward-looking free-entry condition,

$$\frac{k}{q(\vartheta)} = \beta\mathbb{E}\Big[(1-\delta')\,(1-\tilde{\eta}')\,\lambda'\int S(x',\Omega')^{+}dF(x') + (1-\delta')\,(1-\tilde{\eta}')\,(1-\lambda')\int S(x,\Omega')^{+}dG(x)\Big], \tag{16}$$

where $G(x)$ is defined in (6).

3.3 Decentralized equilibrium

The equilibrium of the economy is characterized by solutions to the functional equations for total match surplus (12) and (14), the wage schedules (13) and (15), and the free-entry condition (16), which yield equilibrium total match surplus, the market tightness ratio, and the separation and search cutoffs. The equilibrium of the model retains the block-recursive structure of the standard Mortensen-Pissarides model: one solves for the individual agents' decisions rules and market tightness ratio independently of the stocks of employment, unemployment, and nonparticipation. Then, given the tightness ratio and separation and search cutoffs, one calculates workers' transition probabilities across the three labor market states and the equilibrium dynamics of labor market stocks.

Since the total match surplus is monotonically decreasing in the idiosyncratic shock, x, it is possible to determine two threshold values that uniquely identify the separation cutoff, x^q, and the search cutoff, $x^v \leq x^q$.

Separation cutoff The Nash-bargaining outcome implies that endogenous separations are bilaterally efficient in the sense that employers and individuals agree on the choice of continuing or destroying existing matches. Also, since employers and individuals have the option to separate at no cost, a match continues as long as its value is above zero. Given that match surplus is monotonically decreasing in the worker's valuation of nonmarket work, job separation satisfies the reservation property. That is, there exists a unique separation cutoff, x^q, so that all matches with individuals whose value of nonmarket work is $x \geq x^q$ are endogenously destroyed. Hence, aggregate shocks induce job destruction but the choice of when to separate is chosen by employers and individuals, jointly. This latter event occurs when $S(x^q, \Omega) = 0$, which implicitly defines the cutoff value x^q:

$$hx^q = (1-\tau)\, w\,(x^q, \Omega) + \beta \mathbb{E}\Bigg[\left(1-\delta'\right)\lambda' \int_{x^{\min}}^{x^q} \tilde{\eta}' S(x', \Omega') dF(x') + \left(1-\delta'\right)\left(1-\lambda'\right)\tilde{\eta}' S(x^q, \Omega') \Bigg]. \tag{17}$$

The left-hand side of (17) is the utility cost of market work, whereas the right-hand side is the benefit of market work, which equals the after-tax wage plus the expected discounted value of continuing the employment relationship. Since the cost of posting a job vacancy is sunk at the time of hiring, the cutoff relevant for the job separation decision, x^q, applies to the hiring decision as well.

The tax rate enters the determination of the separation cutoff through two channels. First, the current tax rate affects the per-period return to market work through the after-tax wage, $(1-\tau)\,w\left(x^q,\Omega\right)$. Second, the expectation about the future realization of the tax rate affects the expected total surplus generated by the match in the next period and the share of that surplus retained by the individual through the effective bargaining weight.

Search cutoff The indifference condition between job search and nonparticipation, $U(x^v,\Omega) = H(x^v,\Omega)$, implicitly defines the cutoff value x^v:

$$ax^v = b + (1-\phi)\,p\beta\mathbb{E}\bigg[\left(1-\delta'\right)\lambda'\int_{x^{\min}}^{x^q}\tilde{\eta}'S(x',\Omega')dF(x') \\ + \left(1-\delta'\right)\left(1-\lambda'\right)\tilde{\eta}'S(x^v,\Omega')\bigg]. \tag{18}$$

The left-hand side of (18) is the utility cost of job search, whereas the right-hand side is the benefit of job search, which equals the UI benefit, b, plus the expected discounted value of entering an employment relationship. (Note that the integral on the right-hand side of (18) is defined over the interval $\left[x^{\min}, x^q\right]$ since only matches with positive surplus are created or continued.)

Dynamics of labor market stocks The stocks of employed, e, unemployed, u, and nonparticipants, n, evolve over time according to

$$\begin{bmatrix} e' \\ u' \\ n' \end{bmatrix} = \begin{bmatrix} f_{ee}(\Omega') & f_{ue}(\Omega') & f_{ne}(\Omega') \\ f_{eu}(\Omega') & f_{uu}(\Omega') & f_{nu}(\Omega') \\ f_{en}(\Omega') & f_{un}(\Omega') & f_{nn}(\Omega') \end{bmatrix} \times \begin{bmatrix} e \\ u \\ n \end{bmatrix}, \tag{19}$$

where f_{ij} denotes the individual's transition probability from the labor market state i to j. Here, we briefly describe the determination of these transition probabilities and refer the reader to Appendix B for details on their calculation.

Employed individuals separate from employers either exogenously with probability δ, or endogenously with probability $1-F(x^q)$. Thus, the exogenous stochastic process for δ and the separation cutoff x^q jointly determine the workers' transition probability from employment to unemployment, f_{eu}, from employment to nonparticipation, f_{en}, and the probability of remaining employed, f_{ee}, with the restriction that $f_{eu} + f_{en} + f_{ee} = 1$.

Unemployed individuals meet a posted vacancy with probability $p(\vartheta)$. Time variation in $p(\vartheta)$, resulting from changes in the tightness ratio, ϑ, captures endogenous fluctuations in the degree of labor market frictions. So, the meeting probability, $p(\vartheta)$, the separation, x^q, and participation, x^v, cutoffs jointly determine the workers' transition probability from unemployment to employment, f_{ue}, from unemployment to nonparticipation, f_{un}, and the probability of remaining unemployed, f_{uu}, with the restriction that $f_{ue} + f_{un} + f_{uu} = 1$.

Finally, nonparticipant individuals meet a posted vacancy with probability $\phi p(\vartheta)$. So, the meeting probability $\phi p(\vartheta)$, the separation, x^q, and participation, x^v, cutoffs jointly determine the transition probabilities from nonparticipation to employment, f_{ne}, from nonparticipation to unemployment, f_{nu}, and the probability of remaining nonparticipant, f_{nn}, so that $f_{ne} + f_{nu} + f_{nn} = 1$.

4 Taking the Model to the Data

In this section, we take the model to the data. Following the business cycle literature, we calibrate the model to fit key first- and second-order moments of the U.S. economy. We leave skewness untargeted since it is the main phenomenon we aim to explain.

Parameter values, targeted moments, and data sources are summarized in Table 2. We are to assign values to 21 parameters related to frictions in the labor market (α, $\bar{\delta}$, σ_δ, η, k, ϕ, and χ), individual preferences (β, h, and a), UI benefits, b, and idiosyncratic and aggregate stochastic processes (μ_x, σ_x, $\bar{\lambda}$, σ_λ, $\bar{y}$, ρ_y, σ_y, $\bar{\tau}$, ρ_τ, and σ_τ). The length of a model period is set to one month since key labor market targets are available at a monthly frequency, taken from Krusell et al. (2017). The sample period runs from 1978:M1 to 2012:M9.

4.1 Externally calibrated parameters

We calibrate 8 parameters externally based on common values in the literature. The time discount factor β is set to 0.997 so that the annual risk-free interest rate of our economy equals 4% (see, e.g., McGrattan and Prescott, 2003; Gomme, Ravikumar and Rupert, 2011).

The elasticity of meetings with respect to job searchers, α, is set to 0.5, that is a value consistent with the range of estimates in Petrongolo and Pissarides (2006). Increasing α to 0.7 the upper bound of the estimates in the literature does not affect any of our results. We set the workers' bargaining weight to $\eta = 1 - \alpha = 0.5$, such that the economy meets the Hosios (1990)'s condition absent taxes.

The fixed workweek length, h, is set to 0.2 as in King and Rebelo (1999), and the RBC literature thereafter, to match the average time spent at work which is 20% of the available time in U.S. postwar data. Once the value of h is set, the flow utility cost of job search, a, only enters as a scaling factor of the idiosyncratic shock, thus it is not *separately* identified from the moments of the distribution of the idiosyncratic shock. Hence, we set $a = h$ and calibrate the moments of the distribution of idiosyncratic shock to reproduce the average and the volatility of the participation rate in the data, which we discuss in detail below.

Note also that when $a = h$ the total match surplus of attached employed individuals is independent of x, which effectively mutes the feedback effect from the composition of the pool of searchers to vacancy posting, a feature similar to Mortensen and Pissarides (1994). The idiosyncratic shock x only affects the surplus of the individuals that are marginally attached to the labor force. At any point in time, this category accounts for no more than 10% of employed individuals.

In our baseline calibration, the labor tax rate is constant and set equal to 32%, which is the time-series average of the average marginal tax rate (AMTR) constructed by Barro and Redlick (2011) and widely used in the literature (see, e.g., Mertens and Ravn, 2013). This value is in line with the 30% average effective tax rate in Krusell et al. (2017). When we allow the tax rate to vary stochastically over time, the persistence of the shocks and the volatility of innovations are estimated by fitting the time series of the AMTR to the AR(1) process in (3). Estimation yields $\rho_\tau = 0.985$ and $\sigma_\tau = 0.5\%$ implying substantial variation in tax rates. Notably, shocks to tax rates are highly persistent, which is consistent with the estimates within the context of structural vector autoregressions (see Mertens and Ravn, 2013; Mertens and Montiel-Olea, 2015; Ferraro and Fiori, 2016).

4.2 Internally calibrated parameters

The remaining 13 parameters are calibrated internally to match 13 moments. We discuss heuristically why these moments are particularly informative about some parameters, but the calibration is joint thus in principle all moments inform all parameters.

Based on Shimer (2005), the cost of posting a job vacancy k is set to 0.05 such that the market tightness ratio equals 1 when the stochastic value of a job rests at its median value, which we also normalize to 1 without loss of generality. Given this value of the tightness ratio, we calibrate the mean value of the arrival rate of the idiosyncratic shock, $\bar{\lambda}$, the efficiency of the meeting technology, χ, and the constant probability that a nonparticipant is drawn in the pool of job searchers, ϕ, to jointly match the average probabilities that individuals remain in the current labor market state (f_{ee}, f_{uu}, and f_{nn}). In addition, the mean value of the exogenous job-separation rate, $\bar{\delta}$, is calibrated for the model to match the average transition probability from employment to unemployment, f_{eu}.

The UI benefits parameter b is pinned down at 0.64 to match the cyclical volatility of the employment-to-population ratio in the data. We do so for two reasons. First and foremost, we aim at using the calibrated model as a measurement instrument of the job loss due to cyclical asymmetry. At a minimum, then, one would like to use a model that provides a quantitatively good account of the amplitude of cyclical fluctuations. Second, by calibrating the model to replicate the volatility in the data, one can assess the degree of nonlinearities in the propagation of shocks embedded in the model.

In the model, transitory and persistent shocks to the productivity of a job, y, are the source of aggregate fluctuations. Importantly, we assume that the stochastic process for log productivity follows an AR(1) process, such that it exhibits symmetric fluctuations around its unconditional mean, $\bar{y}$.[8] We normalize $\bar{y}$ to 1 without loss of generality. We set the persistence of the log productivity, ρ_y, to be 0.985, and its conditional volatility, σ_y, to 0.3%, so that the model reproduces the cyclical properties of the quarterly series of labor productivity in the data.[9]

The distribution of idiosyncratic shocks, $F(x)$, is a key element of our calibration. It is assumed to be a (time-invariant) log-normal distribution, whose properties are fully captured by its log-scale parameter, μ_x, and shape σ_x. These parameters jointly determine the mass of individuals *at* or *near* the search and separations cutoffs. We discipline this margin by setting μ_x and σ_x such that the model reproduces the average (66.4%) and the cyclical volatility of the participation rate (0.26%) in the data.

Finally, we are left to calibrate the exogenous stochastic processes for the arrival rate of the idiosyncratic shock, λ, and the exogenous rate of job destruction, δ, that are correlated with the state of the business cycle. The process for λ captures idiosyncratic shifts in the opportunity cost of market work, whereas δ captures the cyclicality in the rate at which jobs are destroyed. We are to assign values to the persistence parameters of the shocks ρ_λ and ρ_δ, and the volatility of the innovations σ_λ and σ_δ.

First, we assume that the stochastic processes for λ and δ have the same persistence and are perfectly correlated with the stochastic output of a job, y. (This modelling choice is appealing as it economizes on the number of exogenous state variables.) Importantly, we identify the sign of this correlation for the model to reproduce the sign of the comovement

[8] Altuğ, Ashley and Patterson (1999) find no evidence for nonlinearity in the Solow residuals in aggregate-level U.S. data and Ilut, Kehrig and Schneider (2017) confirm this finding in establishment-level data.

[9] While the RBC literature emphasize productivity shocks as a source of fluctuations, other shocks play an equally important role (see Ramey, 2016). Here we remain agnostic about the source of business cycles, but shed light on the endogenous propagation mechanism of aggregate shocks to the labor market.

of f_{en} and f_{eu} with output, respectively. This calibration strategy yields a procyclical λ and a countercyclical δ. In expansions (contractions) the arrival rate of the idiosyncratic shocks is higher (smaller) implying that individuals are more (less) likely to change their valuation of nonmarket work. The countercyclicality of δ implies that the probability of exogenous job separations is lower in expansions and higher in contractions, which is consistent with the calibration in Shimer (2005) and many others thereafter. Second, the volatility of the innovations to $\ln(\delta)$ and $\ln(\lambda)$—σ_δ and σ_λ, respectively—are set so that the model reproduces: (i) the volatility of the worker's transition probability from employment to unemployment, f_{eu}; (ii) the comovement of the transition probability from employment to nonparticipation, f_{en}, respectively. (In Section 5, we also present results where λ and δ are constant.)

5 Accounting for the U.S. Business Cycle

In this section, we present the quantitative implications of our calibrated model for the cyclical properties of the U.S. labor market. We begin with a discussion of standard business cycle moments, including volatility, comovement, and persistence of labor market stocks and transition rates. We then evaluate the ability of the model to reproduce the observed skewness or the lack thereof in the data.

To this goal, we simulate the equilibrium of the economy where idiosyncratic shocks to the value of nonmarket work and aggregate shocks to the productivity of a job are drawn from their respective stochastic processes. Tax rates are kept constant. We consider the global nonlinear solution of the model, which preserves potential asymmetries in the equilibrium stochastic processes of endogenous variables (see Appendix C for details on the solution method).

Operationally, we perform 250 simulations, each 870 periods long. We simulate the model at a monthly frequency and then construct quarterly series by averaging the data over three consecutive non-overlapping periods. We discard 40% of the initial series, so we are left with 420 observations that once aggregated at the quarterly frequency match the length of the sample period in Krusell et al. (2017). For each simulation, we compute moments and report the median of those moments across the 250 simulations.

5.1 Standard business cycle moments

We now turn to examine the time-series properties of the calibrated economy in terms of first- and second-order moments of gross worker flows, both labor market stocks and workers' transition probabilities across the three states of the labor market.

Labor market stocks We begin by discussing properties of the model's time series for employment, unemployment, and nonparticipation. While the average participation rate is matched by virtue of our calibration strategy, the average employment-to-population ratio and unemployment rate are left untargeted, yet the model tracks closely their sample averages of 62% and 6.8%, respectively. Thus, in the model, the average *levels* of the stocks are consistent with the data.

Next, we consider the properties of the stocks in *deviations* from trend. Table 3 reports statistics calculated on artificial data simulated from the model, that are aggregated to a quarterly frequency, logged, and HP-filtered with a smoothing parameter of 1600.

The model matches the cyclical volatility of the participation rate and employment-to-population ratio, which are both calibration targets. It generates approximately 90% of the volatility of the unemployment rate in the data. This less than perfect match with the data is due to the fact that the model falls short of replicating the observed correlation between participation and unemployment rates over the business cycle. Importantly, the model generates cyclical volatilities in the vacancy-to-unemployment ratio as well as job vacancies that are remarkably close to the data, thus providing a quantitative explanation of the observed fluctuations in what the model identifies as key determinants of search frictions. As in Hagedorn and Manovskii (2008), the economy-wide replacement rate—the ratio of UI benefits to the *after-tax* average wage rate—is roughly 95%. Calibrating the model to fit the volatility in the data allows us to rigorously assess the extent to which the propagation mechanism of shocks in the model is able to reproduce the skewness (or the lack thereof) in the data.

The model also accounts for the comovement and persistence in the data, measured as the contemporaneous correlation with output and autocorrelation, respectively. Note that none of these moments is a target of our calibration, thus one can assess how well the model does against a rich set of overidentifying restrictions. First, the positive and strong comovement of job vacancies with output is to a large degree not surprising. Intuitively, in the model, shocks to the output of a job are the only source of aggregate fluctuations, so job vacancies are bound to be highly correlated with output. In this sense, a close match with the data along that dimension cannot be viewed as a success. By contrast, the positive comovement of the employment-to-population ratio is not hardwired into the model, but crucially depends upon the specification of parameter values. Our calibrated model generates the strength of the comovement between the unemployment rate and output in the data, and it produces a correlation of the participation rate with output of 0.7, that has the right sign but significantly higher than the 0.2 in the data. We stress that even accounting for the *sign* of the comovement of both unemployment and participation rates has been a challenge for equilibrium models of the aggregate labor market (see Veracierto, 2008; Shimer, 2013).

Second, job vacancies have an autocorrelation of 0.7 that falls short of the 0.9 found in the data. The lack of persistence in vacancies is a well-known problem in search-and-matching models of the labor market. As shown by Fujita and Ramey (2006), one way to tackle this shortcoming is to extend the model with sunk costs in vacancy posting. In our setting, though, the introduction of sunk costs in vacancy posting dramatically increases the state space of the model as the stocks of employed (attached and marginally attached, separately), unemployed, and nonparticipants become endogenous state variables, thus enormously complicating the computation of the equilibrium.

Third, the model generates a downward-sloping Beveridge curve—i.e., the negative empirical relationship between job vacancies and unemployment. This is a well-known challenge for three-state models of the labor market (see, e.g., Tripier, 2004; Veracierto, 2008). Our results along this dimension are in line with Arseneau and Chugh (2012).

Workers' flow rates Table 4 shows averages and business cycle statistics for workers' transition probabilities across employment, unemployment, and nonparticipation in the model and data. We report statistics based on data adjusted for classification errors as in Abowd and Zellner (1985) as well as "de*NUN*ified" data as constructed in Elsby, Hobijn and Şahin (2015).

The model matches the targets of the average flow rates from employment (f_{ee}, f_{eu}, and f_{en}) and accounts reasonably well for those from nonparticipation. In the model, f_{nn}, f_{nu}, and f_{ne} are 0.97, 0.02, and 0.01, that line up closely with their data counterparts of 0.96, 0.02, and 0.02, respectively. The model, though, misses to some degree the average outflow rates from unemployment: it overstates the average transition probability from unemployment to employment, f_{ue}—0.35 in the model, 0.23 in the data—and it largely understates that from unemployment to nonparticipation, f_{un}—0.014 in the model, 0.14 in the data.

Our calibrated model does a good job of accounting for the key cyclical properties of the workers' transition probabilities across labor market states. Notably, it captures the countercyclicality of the unemployment inflow rates (f_{eu} and f_{nu}), the procyclicality of the unemployment outflow rates (f_{ue} and f_{un}), and the procyclicality of the workers' flow rates between employment and nonparticipation (f_{en} and f_{ne}). Although the model is successful in accounting for the comovement of the flow rates with output, it misses in terms of the volatility of fluctuations for some of the flow rates.

While the cyclicality of the flow rates between employment and unemployment (f_{ue} and f_{eu}) can be intuitively rationalized with the cyclical behavior of the job-finding rate and the exogenous job-separation rate, respectively, the cyclical patterns of the flow rates in and out of the labor force deserve more discussion. The procyclicality of the flow rates from employment to nonparticipation, f_{en}, and from unemployment to nonparticipation, f_{un}, depends on the relative strength of competing forces. On the one hand, in good times, the net return of market work is high prompting individuals to remain in the labor force, which other things equal reduces the flow rate to nonparticipation. On the other hand, because of the procyclical arrival rate λ, individuals are more likely to draw idiosyncratic shocks to the value of nonmarket work. This implies that, in equilibrium, the marginal worker features a higher home productivity x^q, relative to the scenario with constant λ. In turn, this increases the mass of marginally attached workers that are more likely, in good times, to choose to drop out of the labor force, thereby increasing the flow rate to nonparticipation. Our calibration implies that the second effect is stronger leading then to the procyclicality of both f_{en} and f_{un} as found in the data. Key to these results is the cyclical variation in the arrival rate of idiosyncratic shocks to the value of nonmarket work. With a constant arrival rate, f_{en} and f_{un} become countercyclical.

5.2 Skewness

We now turn to evaluate the model's ability to generate the cyclical asymmetry in the data, as measured by the skewness of a time series in deviations from trend. Note that, since skewness is not a target of our calibration, a close match to the data constitutes an additional validation of our laboratory economy as a measurement tool.

Overall, the model is successful in reproducing the asymmetry of the employment-to-population ratio discussed in Section 2. As in the data, the cyclical component of the simulated series is extracted applying the Baxter-King filter. The skewness of the artificial series is -0.44, which matches its data counterpart. Importantly, the model reproduces the disconnect between the asymmetry properties of employment and participation rates in the data. In the model, cyclical fluctuations in the employment rate (i.e., one minus the unemployment rate) are left-skewed, with a skewness coefficient of -0.47, whereas those in the participation rate are symmetric, with a skewness coefficient of virtually zero.[10]

5.3 Inspecting the mechanism of fluctuations

To study the propagation mechanism of shocks embodied in the model, we implement two counterfactual experiments. In the first counterfactual, we simulate the model with the market tightness ratio fixed at its steady-state value and allow for variation in the search and separation cutoffs x^v and x^q. In the second counterfactual, we let the tightness ratio to vary and instead fix the cutoffs at their respective steady-state values. In both counterfactuals, we keep the same realizations of the shocks to the output of a job. (Again, tax rates are kept constant.) This exercise yields a (non-additive) decomposition that allows us to disentangle to a large degree the quantitative importance of labor market frictions against labor supply choices.[11]

Volatility Panel A of Table 5 shows the results of the counterfactual analysis regarding the magnitude of fluctuations. Two main insights arise. First, the labor supply effect as captured by fluctuations in the cutoffs accounts for virtually all the cyclical volatility in the participation rate. Second, in the counterfactual economy with a fixed tightness ratio, the volatility of the employment rate drops by nearly two-thirds. Thus, consistently with the empirical findings in Elsby, Hobijn and Şahin (2015), our calibrated economy attributes to the participation margin a quantitatively important role for understanding the magnitude of fluctuations in the unemployment rate.

Skewness Panel B of Table 5 shows results for cyclical asymmetry. First, the slackness effect as captured by endogenous fluctuations in the market tightness ratio accounts for

[10]Note that the success of the model in reproducing the cyclical asymmetry measured in the data is robust to detrending/filtering. If one uses the Christiano and Fitzgerald (2003) filtering method, the skewness of employment-to-population series is -0.20, -0.24 for the employment rate, and 0.00 for the participation rate. Their data counterparts are equal to -0.29, -0.51, and 0.05, respectively. Further, extracting the cyclical component with the Hodrick and Prescott (1997) filter yields a skewness of -0.36 for the employment-to-population (-0.32 in the data), -0.44 for the employment rate (-0.70 in the data), and virtually zero in the participation rate (0.05 in the data).

[11]In the counterfactual experiment with a fixed tightness ratio, we are implicitly assuming the existence of a tax/subsidy to vacancy posting. Concretely, when the aggregate technology shock is below the median state, the tightness ratio is kept at its steady-state value by subsidizing vacancy creation. Conversely, when the technology shock is above the median state, a constant tightness ratio is achieved by taxing vacancy creation.

virtually all the negative skewness in the employment rate. In fact, fluctuations in the cutoffs alone would generate fluctuations in the unemployment rate that are symmetric around trend, which is strongly at odds with the data.

Second, the labor supply effect is the sole responsible for the absence of skewness in the participation rate, whereas fluctuations in the tightness ratio alone generate negative skewness in the participation rate. Thus, we conclude that capturing the relative strength of frictions versus labor supply is key for the model to replicate the disconnect between the asymmetry properties of unemployment and participation rates in the data.

5.4 Importance of idiosyncratic shocks

Table 3 and 4 report an array of results where we shut down idiosyncratic shocks to the job-separation rate, δ, and/or to the probability that an individual changes her valuation of nonmarket work, λ. As these are *exogenous* stochastic processes, here we assess if and to what extent they contribute to the quantitative performance of our calibrated model.

Role of shocks to the job-separation rate In our baseline economy, the exogenous job-separation rate, δ, moves countercyclically. It is of interest to assess its contribution to the overall volatility of the unemployment rate. To this goal, we simulate the model where the shocks to the job-separation rate are shut down, while keeping the other parameters fixed at their baseline values. We find that the volatility of the employment rate is cut by half relative to the baseline, while the volatility of the participation rate is left virtually unchanged. This result lines up nicely with the available empirical estimates of the role of job-separation rates in the U.S. labor market (see Yashiv, 2007; Fujita and Ramey, 2009; Elsby, Michaels and Solon, 2009).

Role of shocks to the value of nonmarket work Shutting down the procyclicality in the arrival rate of shocks to nonmarket work is quantitatively inconsequential for the cyclical properties of labor market stocks. Allowing for procyclical shocks to λ is instead essential for the model to generate the observed positive comovement of f_{en} and f_{un} with output. For future reference, we note that shocks to λ play a quantitatively negligible role in our measurement of the scarring effect of recessions. This near-irrelevance result is reassuring, as it makes our measurement robust to alternative specifications of home production.

6 Quantitative Implications for the U.S. Economy

So far we showed that our parsimonious model accounts reasonably well for the cyclical properties of the U.S. labor market, both in terms of standard business cycle moments and skewness (or the lack thereof) in the data. Having established this success, we next use the calibrated model to quantify the job loss due to asymmetric business cycles. Then, we ask to what extent countercyclical tax policy can attenuate this job loss.

6.1 The scarring effect of the asymmetric business cycle

In the presence of cyclical asymmetry, aggregate fluctuations have a permanent effect on the average *level* of economic activity. Hereafter, we refer to this effect as "scar." To operationalize this concept, we measure the scar as the difference between the ergodic mean of the equilibrium stochastic processes for aggregate employment and its respective value in the stochastic steady state of the model. The latter is defined as the median point in the support of the "stationary equilibrium," that obtains when the distribution of equilibrium variables across states reproduces itself.

Our approach to the measurement of the scar is appealing for two reasons. First, the scar is by construction zero in the *linearized* version of our model, but generally different from zero since the model is inherently nonlinear; it exhibits curvature in the mapping between shocks to the output of a job and aggregate employment and output. Second, it provides an intuitive, and yet theoretically-based statistic that quantifies the importance of nonlinearities for aggregate outcomes.

Panel C of Table 5 reports our measurement of the scar. Through the lens of our model, we measure the scar to be 0.3 percentage points of the employment-to-population ratio. The bulk of this job loss is due to the employment rate which would be 0.4 percentage points higher in the absence of cyclical fluctuations. We find virtually no scarring effect on the participation rate. Importantly, we find that endogenous fluctuations in the level of frictions are the sole responsible of the estimated job loss. (See Appendix D for further results on the measurement of the scar when shocks to the job-separation rate and value of nonmarket work are shut down.)

Our results carry important methodological implications and thus suggests a hitherto unexplored motive for stabilization policy. First, from a methodological point of view, our results challenge the conventional approach in the literature where fluctuations are viewed as symmetric around the trend. In that view, typically obtained within linearized or close-to-linear equilibrium models, the benefits of stabilization policies arise to the extent that risk-averse consumers dislike fluctuations. In that context, Lucas (1987) shows that reducing the volatility of the business cycle would have limited welfare effects, quantified in about a tenth of a percentage point of aggregate consumption. When business cycles are asymmetric, the volatility of fluctuations determines the average level of economic activity with first-order welfare effects. Second, policy actions may either exacerbate or attenuate labor market scars. Erratic tax changes, unrelated to business cycle conditions, contribute to labor market fluctuations and therefore add to the scarring effect. Instead, systematic, countercyclical tax policy has beneficial effects that extend beyond reducing the amplitude of business cycles as they also lead to gains in the average level of aggregate labor and output.

6.2 The benefits of countercyclical stabilization policy

We now turn to examine the time-series properties of the equilibrium in the presence of countercyclical tax policy. To this aim, we compare two scenarios. First, we take as a benchmark our baseline economy in which the tax rate is fixed at the sample average of 32%. Second, we consider an alternative economy in which a simple *rule* makes the labor tax rate perfectly positively correlated with the stochastic output of the job. As a result, the tax rate fluctuates symmetrically around the 32% level. In doing so, we compare two economies that have on average the same level of the tax rate, but differ in terms of the tax rate's systematic response to aggregate conditions only.

Few remarks are in order. First, we do not take a stand on whether the procyclical variation in the tax rate comes from active policy interventions or automatic stabilizers as to a large degree it is inconsequential for our argument. Second, a full-blown optimal taxation exercise is beyond the scope of this paper. Here we consider a simple policy rule and assess how far it goes in reducing the scar.

Figure 1 shows impulse response functions (IRFs) to a 1% shock to the output of a job. For both scenarios, IRFs are computed initializing the economy at its stochastic steady state. We start by describing the baseline scenario, where the tax rate is constant (blue-triangled lines). The lower (upper) panel reports the IRFs to a negative (positive) shock to the output of a job that reduces (increases) the instantaneous return to the total surplus of a match. As a result, vacancy posting drops leading to a reduction in the job-finding rate and an increase in the unemployment rate. A lower match surplus also reduces the incentives to join and/or stay in the labor force leading to higher separation and a drop in the labor force participation rate and in the number of employed. Overall, the calibrated model exhibits a great deal of internal propagation: IRFs are hump-shaped with the peak responses occurring one or more years after the initial shock.

Before turning to the IRFs obtained under the procyclical tax rule, it is instructive to discuss the propagation mechanism of tax shocks—i.e., temporary and unexpected changes in the labor tax rate. To fix ideas, we describe the scenario of a reduction in the tax rate. A lower tax rate increases total match surplus through three channels: (i) it raises the per-period return to the match by reducing the opportunity cost of market work; (ii) it raises the individual's effective bargaining weight, such that the employee retains a larger share of the total match surplus; and (iii) it heightens the incentives to vacancy posting, leading to a raise in equilibrium market tightness. This latter equilibrium effect raises expected match surplus through the free-entry condition.

In Appendix D, we report IRFs of labor market variables to a tax shock. Qualitatively, the dynamic responses to tax shocks are similar to those in Figure 1. A lower tax rate increases the match surplus with beneficial effects for job creation and participation that improve aggregate labor market outcomes.

In Figure 1, red-squared lines show IRFs under countercyclical tax policy. Tax hikes (upper panels) or cuts (lower panels) stabilize the match surplus by counteracting shocks to the value of a job. As a result, labor market fluctuations are dampened. As evident from Figure 1, the presence of the tax policy rule greatly affects the cyclical properties of the labor market with a marked reduction in the volatility of all series, that is lowered by two-thirds relative to the baseline case. Labor market asymmetry is also affected with the skewness of the employment-to-population ratio dropping from -0.44 to -0.2.

The main takeaway is that the reduction in the volatility and asymmetry of business cycle fluctuations increases average employment by 0.2 percentage points, "healing" to a large extent the labor market scar. Our results bear important consequences for the design and conduct of tax policy. Our contribution is to show that a purposeful use of tax policy not only reduces the magnitude of aggregate fluctuations but, by doing so, it also increases the average level of employment around which the economy fluctuates.

In addition, our findings point to the adverse effects of tax uncertainty. Temporary fluctuations in the tax rate around a given mean, unrelated to business cycle conditions, are a source of employment losses. This result stems from the concavity of aggregate employment with respect to the tax rate implied by the equilibrium of the model. In this sense, the transmission mechanism of shocks at play in the model provides a rationale for the tax-smoothing argument in Barro (1979).

7 Conclusion

The U.S. employment-to-population ratio moves asymmetrically over the business cycle: deviations below trend (troughs) are larger than deviations above trend (peaks). This pattern generates significant negative skewness in the distribution of the employment-to-population ratio in deviations from trend. Nearly all of this skewness is accounted by the unemployment rate as the labor force participation rate moves symmetrically over the business cycle.

To explain these facts, we formulate an equilibrium business cycle model featuring frictional unemployment and a labor force participation decision. The model, restricted to fit key observations of U.S. data, including gross worker flows between employment, unemployment, and nonparticipation, accounts for the observed cyclical skewness in the unemployment rate and the lack thereof in the participation rate. It is worth noticing that in the model participation decisions are quantitatively important to understand the magnitude of fluctuations in the unemployment rate, consistently with the evidence in Elsby, Hobijn and Şahin (2015).

The key lesson of our quantitative analysis is that the asymmetric business cycle has a "scarring effect," which reduces the average level of economic activity around which the economy fluctuates. Trough the lens of our model, we estimate that the employment-to-population ratio would be 0.3 percentage points higher (or, equivalently, a gain of about a million jobs) in the absence of aggregate fluctuations. Search frictions are the primary source of this job loss. Overall, the paper quantifies the implications of nonlinearities in business cycle fluctuations and provides a novel rationale for countercyclical stabilization policy.

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Tables and Figures

Table 1: Skewness in the U.S. Labor Market

	Skewness		
	Baxter-King	Christiano-Fitzgerald	Hodrick-Prescott
A. Sample period: 1948:Q1-2016:Q4			
Employment-to-population ratio	-0.44	-0.29	-0.32
	(0.02)	(0.08)	(0.03)
Employment rate	-0.85	-0.51	-0.70
	(0.00)	(0.00)	(0.00)
Participation rate	0.09	0.05	0.05
	(0.38)	(0.44)	(0.38)
B. Sample period: 1948:Q1-1980:Q4			
Employment-to-population ratio	-0.42	-0.34	-0.43
	(0.03)	(0.05)	(0.02)
Employment rate	-0.80	-0.62	-0.76
	(0.00)	(0.01)	(0.00)
Participation rate	0.12	0.03	-0.06
	(0.34)	(0.45)	(0.41)

Notes: For the Baxter-King and Christiano-Fitzgerald filters, we consider frequencies between 2 and 32 quarters. The order of the moving average for the Baxter-King filter is 8 quarters. The smoothing parameter for the Hodrick-Prescott filter is 1600. Variables are expressed in log-deviations from trend. P-values (one-sided test) in parentheses.

Table 2: Calibrated Parameter Values

Parameter	Description	Value	Target/Source
A. Labor market frictions			
α	Elasticity of meetings to searchers	0.500	Literature
$\bar{\delta}$	Exogenous separation rate: mean	0.015	Flow rate f_{eu}: average
σ_δ	Exogenous separation rate: volatility	0.041	Flow rate f_{eu}: volatility
η	Workers' bargaining weight	0.500	Literature
κ	Unit vacancy cost	0.050	Steady-state tightness
ϕ	Probability of becoming searcher	0.850	Flow rate f_{nn}: average
χ	Meeting efficiency	0.365	Flow rate f_{uu}: average
B. Individual preferences and UI benefits			
β	Time discount factor	0.997	4% real interest rate
h	Utility cost of market work	0.200	Literature
a	Utility cost of search	0.200	Normalization
b	UI benefit	0.639	Emp/pop: volatility
C. Aggregate stochastic processes			
$\bar{y}$	Productivity shock: mean	1.000	Normalization
ρ_y	Productivity shock: persistence	0.985	Fit to AR(1)
σ_y	Productivity shock: volatility	0.003	Fit to AR(1)
$\bar{\tau}$	Tax shock: mean	0.320	AMTR: average
ρ_τ	Tax shock: persistence	0.985	Fit to AR(1)
σ_τ	Tax shock: volatility	0.005	Fit to AR(1)
D. Idiosyncratic stochastic process			
μ_x	Log-normal: scale	0.960	Participation rate: average
σ_x	Log-normal: shape	0.630	Participation rate: volatility
$\bar{\lambda}$	Arrival rate: mean	0.040	Flow rate f_{ee}: average
σ_λ	Arrival rate: volatility	0.008	Flow rate f_{en}: comovement

Table 3: Business Cycle Statistics: Labor Market Stocks

	y	v/u	v	EPOP	ER	PR
A. Standard deviation						
Data	0.75	24.01	13.15	0.99	0.90	0.26
Model: baseline	0.75	22.94	13.06	0.99	0.79	0.26
Model: $\sigma_\delta = \sigma_\lambda = 0$	0.75	19.28	12.82	0.67	0.50	0.24
Model: $\sigma_\lambda = 0$	0.75	24.07	13.05	1.03	0.84	0.24
Model: $\sigma_\delta = 0$	0.75	18.91	12.81	0.63	0.45	0.24
B. Correlation with output						
Data	0.55	0.89	0.88	0.83	0.86	0.21
Model: baseline	0.93	0.98	0.90	0.96	0.97	0.69
Model: $\sigma_\delta = \sigma_\lambda = 0$	0.94	0.97	0.91	0.93	0.95	0.67
Model: $\sigma_\lambda = 0$	0.93	0.98	0.91	0.96	0.97	0.70
Model: $\sigma_\delta = 0$	0.94	0.97	0.91	0.94	0.96	0.67
C. Autocorrelation						
Data	0.76	0.92	0.91	0.92	0.93	0.69
Model: baseline	0.76	0.82	0.73	0.88	0.86	0.89
Model: $\sigma_\delta = \sigma_\lambda = 0$	0.76	0.82	0.81	0.92	0.88	0.96
Model: $\sigma_\lambda = 0$	0.75	0.76	0.82	0.88	0.86	0.94
Model: $\sigma_\delta = 0$	0.76	0.81	0.74	0.88	0.85	0.94
D. Beveridge curve						
Data	-0.92					
Model: baseline	-0.84					
Model: $\sigma_\delta = \sigma_\lambda = 0$	-0.82					
Model: $\sigma_\lambda = 0$	-0.84					
Model: $\sigma_\delta = 0$	-0.81					

Notes: y denotes the stochastic output of a job; v job vacancies; u unemployed; EPOP the employment-to-population ratio; ER the employment rate (i.e., one minus the unemployment rate); and PR the participation rate. Actual and model variables are quarterly averages of monthly series expressed in log-deviations from the Hodrick-Prescott trend with smoothing parameter 1600. See Appendix A for data sources.

Table 4: Business Cycle Statistics: Workers' Transition Probabilities

	f_{eu}	f_{en}	f_{ue}	f_{un}	f_{ne}	f_{nu}
A. Average						
Data: AZ-adjusted	0.014	0.014	0.228	0.135	0.022	0.021
Model: baseline	0.014	0.014	0.349	0.014	0.010	0.018
Model: $\sigma_\delta = \sigma_\lambda = 0$	0.014	0.014	0.351	0.014	0.010	0.018
Model: $\sigma_\lambda = 0$	0.014	0.014	0.347	0.014	0.010	0.018
Model: $\sigma_\delta = 0$	0.014	0.014	0.350	0.014	0.010	0.018
B. Standard deviation						
Data: AZ-adjusted	0.089	0.083	0.088	0.106	0.103	0.072
Data: De*NUN*ified	0.069	0.036	0.076	0.066	0.041	0.063
Model: baseline	0.089	0.004	0.074	0.010	0.081	0.013
Model: $\sigma_\delta = \sigma_\lambda = 0$	0.002	0.011	0.069	0.008	0.071	0.027
Model: $\sigma_\lambda = 0$	0.084	0.016	0.075	0.008	0.067	0.029
Model: $\sigma_\delta = 0$	0.002	0.006	0.069	0.010	0.085	0.011
C. Correlation with output						
Data: AZ-adjusted	-0.630	0.430	0.760	0.610	0.520	-0.230
Data: De*NUN*ified	-0.660	0.290	0.810	0.550	0.570	-0.560
Model: baseline	-0.921	0.430	0.968	0.927	0.974	-0.872
Model: $\sigma_\delta = \sigma_\lambda = 0$	-0.599	-0.885	0.964	-0.944	0.970	-0.968
Model: $\sigma_\lambda = 0$	-0.920	-0.893	0.970	-0.938	0.965	-0.968
Model: $\sigma_\delta = 0$	-0.687	0.986	0.961	0.928	0.972	-0.830
D. Autocorrelation						
Data: AZ-adjusted	0.590	0.290	0.750	0.620	0.380	0.300
Data: De*NUN*ified	0.700	0.220	0.850	0.580	0.480	0.570
Model: baseline	0.767	0.872	0.766	0.742	0.756	0.551
Model: $\sigma_\delta = \sigma_\lambda = 0$	0.949	0.750	0.760	0.783	0.758	0.764
Model: $\sigma_\lambda = 0$	0.762	0.748	0.759	0.777	0.765	0.762
Model: $\sigma_\delta = 0$	0.946	0.816	0.761	0.740	0.767	0.482

Notes: f_{ij} indicates the transition probability from state i to j; e stands for employment, u for unemployment, and n for the nonparticipation state. All variables are quarterly averages of monthly series expressed in log-deviations from the Hodrick-Prescott trend with smoothing parameter 1600. See Appendix A for data sources.

Table 5: Counterfactual Experiments

	Model	Ctrfl 1 (fixed tightness)	Ctrfl 2 (fixed cutoffs)
A. Standard deviation			
Employment-to-population ratio	0.99	0.44	0.82
Employment rate	0.79	0.25	0.78
Participation rate	0.26	0.23	0.05
B. Skewness			
Employment-to-population ratio	-0.44	0.03	-0.45
Employment rate	-0.47	0.00	-0.46
Participation rate	0.00	0.03	-0.40
C. Scar			
Employment-to-population ratio	-0.30	-0.04	-0.26
Employment rate	-0.42	-0.02	-0.37
Participation rate	0.03	0.03	0.02

Notes: "Ctrfl 1" refers to the counterfactual experiment where the model is simulated with the tightness ratio fixed at its steady-state value and varying search and separation cutoffs. "Ctrfl 2" refers to the counterfactual experiment where the model is simulated with cutoffs fixed at their steady-state values and varying tightness ratio. In both counterfactuals, we keep the same realizations of the shocks to the output of a job.

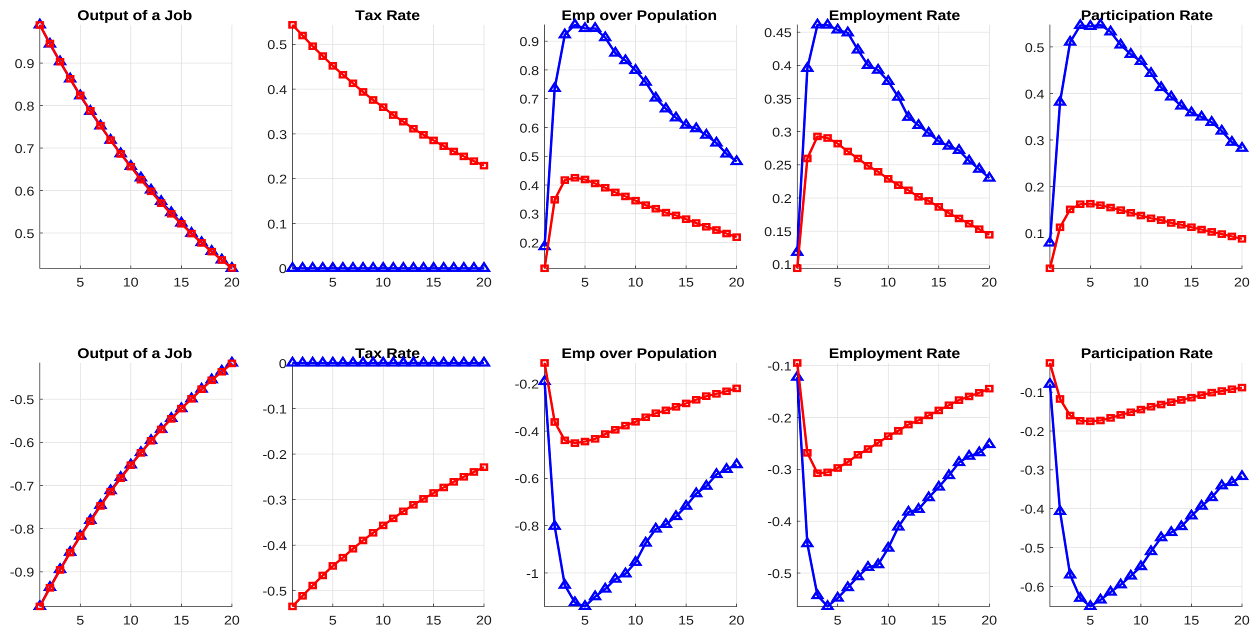

Figure 1: Shock to the output of a job under countercyclical (red-squared line) and constant tax rate (blue-triangled line). Responses show deviations expressed in percentage points from steady-state values. Each period represents a quarter.

APPENDIX

A Data Sources

Data for the monthly and seasonally-adjusted unemployment rate (series LNS14000000) and participation rate (series LNS11300000) are from the Current Population Survey (CPS) of the Bureau of Labor and Statistics (BLS) and available at the BLS website at www.bls.gov. The employment-to-population ratio is obtained as one minus the unemployment rate times the participation rate. Data for monthly hazard rates across different states (employment, unemployment, and nonparticipation) are taken from Krusell et al. (2017). Data for job vacancies are the monthly composite Help-Wanted Index (HWI) constructed by Barnichon (2010) and available at the author's website at https://sites.google.com/site/regisbarnichon. Quarterly data are obtained by averaging non-overlapping monthly observations in a given quarter. Seasonally-adjusted quarterly data for real output per worker in nonfarm business sector are produced by the BLS and available at the Labor Productivity and Costs (LPC) home page at http://www.bls.gov/lpc. The time series for the average marginal tax rate (AMTR) is from Mertens and Montiel-Olea (2015).

B Model Derivations

B.1 Gross worker flows

Let f_{ij} denote the worker's transition probability from the labor market state i to j. Also, we use a, m, and n as subscripts to indicate "attached," "marginally attached," and "non-attached" individuals, respectively, and primes to denote next period variables. Stocks of employed, e, unemployed, u, and nonparticipants, n, evolve over time according to

$$e'_a = f'_{e_a e_a} e_a + f'_{e_m e_a} e_m + f'_{u e_a} u + f'_{n_m e_a} n_m + f'_{n_n e_a} n_n, \tag{B.1}$$

$$e'_m = f'_{e_a e_m} e_a + f'_{e_m e_m} e_m + f'_{u e_m} u + f'_{n_m e_m} n_m + f'_{n_n e_m} n_n, \tag{B.2}$$

$$u' = f'_{e_a u} e_a + f'_{e_m u} e_m + f'_{uu} u + f'_{n_m u} n_m + f'_{n_n u} n_n, \tag{B.3}$$

$$n'_m = f'_{e_a n_m} e_a + f'_{e_m n_m} e_m + f'_{u n_m} u + f'_{n_m n_m} n_m + f'_{n_n n_m} n_n, \tag{B.4}$$

$$n'_n = f'_{e_a n_n} e_a + f'_{e_m n_n} e_m + f'_{u n_n} u + f'_{n_m n_n} n_m + f'_{n_n n_n} n_n. \tag{B.5}$$

The transition probabilities are calculated as:

$$f'_{e_a e_a} = \left(1-\delta'\right)\left\{1-\lambda'\left[1-F\left(x^v\right)\right]\right\}, \tag{B.6}$$
$$f'_{e_m e_a} = \left(1-\delta'\right)\lambda' F\left(x^v\right), \tag{B.7}$$
$$f'_{u e_a} = p\left(1-\delta'\right)\left\{1-\lambda'\left[1-F\left(x^v\right)\right]\right\}, \tag{B.8}$$
$$f'_{n_m e_a} = \phi p\left(1-\delta'\right)\lambda' F\left(x^v\right), \tag{B.9}$$
$$f'_{n_n e_a} = \phi p\left(1-\delta'\right)\lambda' F\left(x^v\right), \tag{B.10}$$
$$f'_{e_a e_m} = \left(1-\delta'\right)\lambda'\left[F\left(x^q\right)-F\left(x^v\right)\right], \tag{B.11}$$
$$f'_{e_m e_m} = \left(1-\delta'\right)\left\{1-\lambda' F\left(x^v\right)-\lambda'\left[1-F\left(x^q\right)\right]\right\}, \tag{B.12}$$
$$f'_{u e_m} = p\left(1-\delta'\right)\lambda'\left[F\left(x^q\right)-F\left(x^v\right)\right], \tag{B.13}$$
$$f'_{n_m e_m} = \phi p\left(1-\delta'\right)\left\{1-\lambda'\left[1-F\left(x^q\right)\right]-\lambda' F\left(x^v\right)\right\}, \tag{B.14}$$
$$f'_{n_n e_m} = \phi p\left(1-\delta'\right)\lambda'\left[F\left(x^q\right)-F\left(x^v\right)\right], \tag{B.15}$$
$$f'_{e_a u} = \delta'\left\{1-\lambda'\left[1-F\left(x^v\right)\right]\right\}, \tag{B.16}$$
$$f'_{e_m u} = \delta'\lambda' F\left(x^v\right), \tag{B.17}$$
$$f'_{uu} = \left[1-p\left(1-\delta'\right)\right]\left\{1-\lambda'\left[1-F\left(x^v\right)\right]\right\}, \tag{B.18}$$
$$f'_{n_m u} = \left[1-\phi p\left(1-\delta'\right)\right]\lambda' F\left(x^v\right), \tag{B.19}$$
$$f'_{n_n u} = \left[1-\phi p\left(1-\delta'\right)\right]\lambda' F\left(x^v\right), \tag{B.20}$$
$$f'_{e_a n_m} = \delta'\lambda'\left[F\left(x^q\right)-F\left(x^v\right)\right], \tag{B.21}$$
$$f'_{e_m n_m} = \delta'\left\{1-\lambda' F\left(x^v\right)-\lambda'\left[1-F\left(x^q\right)\right]\right\}, \tag{B.22}$$
$$f'_{u n_m} = \lambda'\left[1-p\left(1-\delta'\right)\right]\left[F(x^q)-F(x^v)\right], \tag{B.23}$$
$$f'_{n_m n_m} = \left[1-\phi p\left(1-\delta'\right)\right]\left\{1-\lambda' F\left(x^v\right)-\lambda'\left[1-F(x^q)\right]\right\}, \tag{B.24}$$
$$f'_{n_n n_m} = \lambda'\left[1-\phi p\left(1-\delta'\right)\right]\left[F(x^q)-F(x^v)\right], \tag{B.25}$$
$$f'_{e_a n_n} = \lambda'\left[1-F\left(x^q\right)\right], \tag{B.26}$$
$$f'_{e_m n_n} = \lambda'\left[1-F\left(x^q\right)\right], \tag{B.27}$$
$$f'_{u n_n} = \lambda'\left[1-F\left(x^q\right)\right], \tag{B.28}$$
$$f'_{n_m n_n} = \lambda'\left[1-F\left(x^q\right)\right], \tag{B.29}$$
$$f'_{n_n n_n} = 1-\lambda' F\left(x^q\right). \tag{B.30}$$

C Solution Method

We solve the model numerically by value function iteration. This global solution method preserves potential non-linearities in the propagation mechanism of shocks. We start by discretizing the two continuous processes for productivity and the tax shocks using the Tauchen (1986)'s method. For each process we use a grid with $N_y = N_\tau = 17$ points. The distribution of the idiosyncratic shocks is discretized using 6000 points and truncated with a cutoff $x^{\max} = 6$. The p.d.f. evaluated at $x^{\max}$ is equal to 0.0000 and the c.d.f. at $1 - x^{\max}$ is equal to 0.09. Increasing the number of points on the grid for the aggregate and idiosyncratic shocks does not affect the results. In addition to the law of motions for the exogenous stochastic processes, the equilibrium is characterized by 5 equations: the Bellman equations for the total match surplus (12) and (14), the free-entry condition (16), and the indifference conditions (17) and (18) determining the separation and search cutoffs, respectively.

We compute the equilibrium of the model via backward recursion. We start with a guess for the surplus and the cutoffs. The free-entry condition allows us to recover the market tightness ratio, ϑ, conditional on each realization of the aggregate shocks. Given ϑ, we compute the total surplus for each idiosyncratic and aggregate state. Finally, the separation and the search cutoffs are obtained. This recursive procedure is iterated until convergence that follows as a consequence of the saddle-point stability property of the model, which makes for stability in the backward dynamics. Then, with the value function computed at grid points we interpolate for in-between values. This is done using a multidimensional cubic splines procedure, with a so-called "not-a-knot"-condition to address the large number of degrees of freedom problem, when using splines (see Judd, 1998). This allows us to simulate the model over a continuous support for the stochastic processes and to conveniently compute nonlinear impulse response functions (IRFs).

D Additional Results

D.1 IRFs to a tax shock

Here we report IRFs to an unanticipated tax cut/hike of half a percentage point. The size of the shock is in line with the endogenous response of the tax rate implied by the countercyclical tax policy rule in Figure 1.

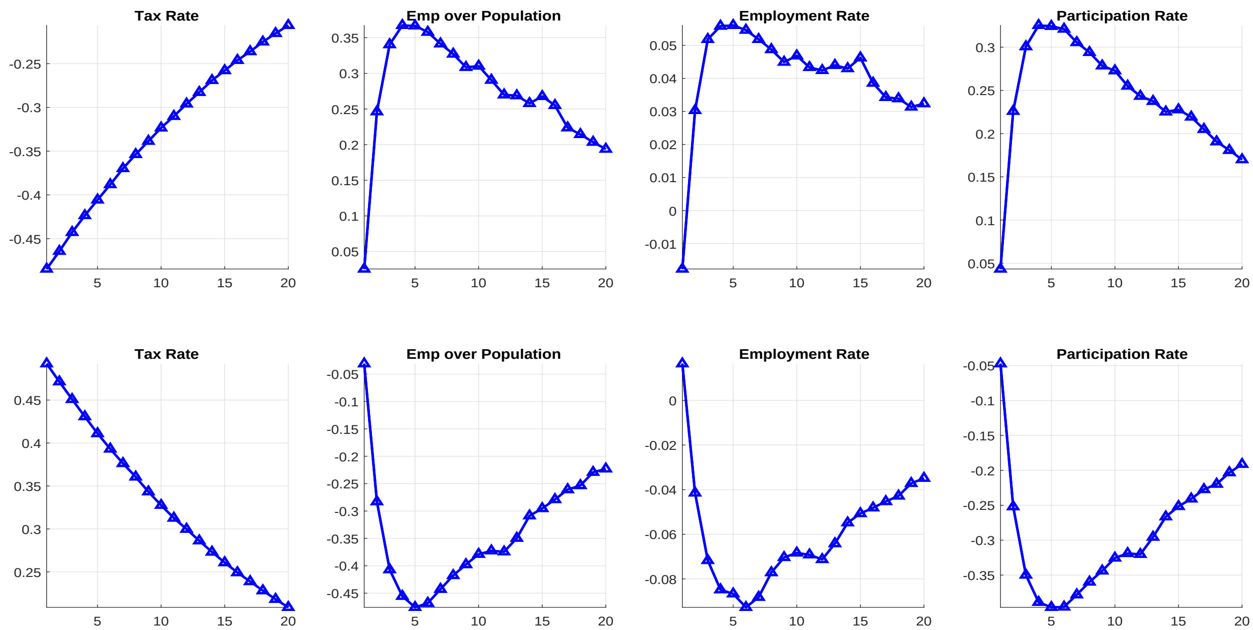

Figure $D.1$: Impulse responses to a discretionary tax shock, keeping the output of a job fixed at its steady-state value. Responses show deviations expressed in percentage points from steady-state values. Each period represents a quarter.

D.2 Shutting down idiosyncratic risk

Here we report results that confirm the robustness of our counterfactual analysis to shutting down cyclicality in the value of nonmarket work and the exogenous job-separation rate. To this goal, we fix λ and δ at their respective steady-state values.

In the first counterfactual, we simulate the model with the market tightness ratio fixed at its steady-state value and allow for variation in the search and separation cutoffs x^v and x^q. In the second counterfactual, we let the tightness ratio to vary and instead fix the cutoffs at their respective steady-state values. We keep the same realizations of the shocks to the output of a job (and a constant tax rate) in both counterfactuals.

Table D.1: Counterfactual Experiments without Idiosyncratic Risk

	Model	Ctrfl 1 (fixed tightness)	Ctrfl 2 (fixed cutoffs)
A. Standard deviation			
Employment-to-population ratio	0.67	0.24	0.51
Employment rate	0.50	0.02	0.48
Participation rate	0.24	0.22	0.03
B. Skewness			
Employment-to-population ratio	-0.42	-0.02	-0.48
Employment rate	-0.50	-0.01	-0.48
Participation rate	-0.02	-0.04	-0.44
C. Scar			
Employment-to-population ratio	-0.26	-0.06	-0.20
Employment rate	-0.30	-0.01	-0.29
Participation rate	-0.05	-0.05	-0.01

Notes: "Ctrfl 1" refers to the counterfactual experiment where the model is simulated with the tightness ratio fixed at its steady-state value and varying search and separation cutoffs. "Ctrfl 2" refers to the counterfactual experiment where the model is simulated with cutoffs fixed at their steady-state values and varying tightness ratio. In both counterfactuals, we keep the same realizations of the shocks to the output of a job, and λ and δ are fixed at their steady-state values $\bar{\lambda}$ and $\bar{\delta}$, respectively.