Job Displacement and the Cost of Business Cycles*

Karl Walentin† and Andreas Westermark‡

Preliminary version. Please do not quote.

February 15, 2016

Abstract

We document a new mechanism for which cyclical variation in the unemployment rate reduces the aggregate level of output and welfare. Our mechanism concerns the earnings losses generated by job displacement. It has been broadly established that this type of earnings losses are large. We rely on the empirical results of Davis and von Wachter (2011) who document that both the frequency of job displacement and the earnings losses per displaced worker are increasing in the unemployment rate. We model the above phenomenon in a general equilibrium framework which accounts for heterogeneity on both the firm and worker side. We quantify the effect of business cycles and find that they reduce GDP by 1.5%.

Keywords: Search and matching, earnings loss, labor market, human capital

JEL classification: E32, J31.

*We are grateful to Per Krusell, Claudio Michelacci and conference participants at Normac, Uppsala University and our discussant Oskari Vähämaa for useful comments and discussions. The opinions expressed in this article are the sole responsibility of the authors and should not be interpreted as reflecting the views of Sveriges Riksbank.

†Research Department, Sveriges Riksbank, SE-103 37, Stockholm, Sweden. e-mail: karl.walentin@riksbank.se.

‡Research Department, Sveriges Riksbank, SE-103 37, Stockholm, Sweden. e-mail: andreas.westermark@riksbank.se.

1 Introduction

A major question in macroeconomics is whether welfare costs of business cycles are substantial or not. Since Lucas (1987) it has been well established that the cost of aggregate consumption fluctuations is very small. Business cycles can induce welfare costs in other ways as well, e.g. through their effect on the cross-sectional distribution of consumption (Imrohoroğlu, 1989, and many others). A third way in which business cycles may affect welfare is through the level of output. Two examples of such models are Mertens and Hassan (2014), by financial channels, and Den Haan and Sedlacek (2014), by limitations in contracts within a employer-employee match.

In this paper, we show that cyclical variation in the unemployment rate reduces the aggregate level of employment, output and welfare. Our mechanism concerns the earnings losses generated by job displacement. It has been broadly established that this type of earnings losses are large. We rely on the empirical results of Davis and von Wachter (2011), DvW henceforth. They document that both the frequency of job displacement and the present discounted earnings losses per displaced worker are increasing in the unemployment rate.[1] Together, these two facts imply that displacement occurs at a higher frequency in times when it is more costly. An economy with the same average displacement rate but without any unemployment volatility would yield lower aggregate earnings losses due to displacement. Our simple model-free calculations indicate that the cyclicality in unemployment generate a quarter of the empirically observed earnings losses. This corresponds to more than 1% of GDP. These losses due to job displacement constitute an overlooked potential component of the welfare costs of business cycles.

We model the above phenomenon in a general equilibrium framework with a search and matching labor market. The two key facts mentioned above drive the key mechanism in our model and therefore need to be captured well. To generate the first fact, the countercyclicality of job displacement, is straight forward and achieved by modelling endogenous separations of jobs. The second fact, that earnings losses per displaced worker are increasing in the unemployment rate, follows from longer unemployment spells and lower job-to-job transitions in recessions and is amplified by human capital loss during unemployment.

Our model accounts for heterogeneity on both the firm and worker side. Firms differ in match quality and workers in the level of human capital. Both types of idiosyncratic variation is subject to shocks. For human capital, we assume that workers gain human capital while on the job, and loose human capital when unemployed. Both unemployed and employed workers search for jobs, i.e. we

[1] Similar empirical results are documented in Jacobson et al (1993) and Farber (2005).

allow for on-the-job search. On the job search leads to a job ladder mechanism that is important for generating persistent earnings losses from displacement (see Burdett, Carrillo-Tudela and Coles, 2015, Huckfeldt, 2014 and Krolikowski, 2014).

To enable us to draw quantitative implications from the model, we calibrate it by matching a large number of moments, including the degree of wage dispersion, the cyclicality of job separations and the cyclical variation in earnings losses per worker. We then compute the welfare costs of business cycles by comparing the results from the full model to the results from a model without aggregate shocks. We find that in our model the presence of aggregate shocks reduce GDP (employment) by 1.5% (1.1%). This is a large effect on GDP and roughly in line with the extra earning losses of workers induced by cycles in the data. In other words, losses of employers and indirect effects contribute a small positive amount to the total output losses. We note that the effect goes through both labor productivity (human capital and match quality) and the employment level. But the key force is the human capital dynamics. When we turn off the human capital dynamics in our model the GDP losses from business cycles are negligible.

The welfare effects of the mechanism we are documenting works through the level of output. In this sense it is fundamentally different from Krebs (2007), where the costs of business cycles consists of individual consumption volatility due to idiosyncratic countercyclical labor income risk related to job displacement. We have abstracted from this type of mechanism by assuming risk-neutrality.[2] In terms of aggregate implications our paper is related to Den Haan and Sedlacek (2014). They explore the welfare cost of business cycles in a setting where an agency problem generates inefficient job separations in downturns. In their model, eliminating business cycles therefore reduces the average job separation rate. Our framework does not include any such agency problem. In fact, the role of market imperfections for the cost of business cycles is negligible in our setting.

Following the challenge presented by DvW, a number of papers have emerged that set up models to replicate the large earnings losses observed following displacement. Jarosch (2014), Jung and Kuhn (2014) and Krolikowski (2014) does so for a fixed aggregate state. Burdett, Carrillo-Tudela and Coles (2015) perform the analysis along a deterministic growth path and in their model human capital loss is important for the size and persistence of earnings loss. Huckfeldt (2014) in addition captures some of the cyclicality of earnings losses. No previous paper explores the loss of output and welfare generated by the cyclical variation of job displacement and the related earnings losses.

[2] It is also distinct from the mechanism in Krebs (2003). There countercyclical idiosyncratic income risk imply that business cycles reduce human capital investment, and for low values of risk aversion, total investment.

This paper is outlined as follows: In Section 2 we describe some evidence motivating our exercise. Section 3 presents the model, Section 4 the calibration and Section 5 the quantitative results. Finally, Section 6 concludes.

2 Motivating empirics

The main exercise of this paper is to quantify the costs of business cycles due to job displacement and the corresponding earnings losses. The key intuition for our mechanism is that both the frequency of job displacement and earnings losses per displaced worker are increasing in the unemployment rate, implying that aggregate earnings losses are convex in the unemployment rate.

Let us here refer to the evidence that both the frequency of job displacement and earnings losses per displaced worker are increasing in the unemployment rate. Table 1 presents Davis and von Wachter's results clearly indicating that earnings losses from displacement are increasing in the unemployment rate. Note, for example, the fact that earnings losses are twice as high (in % of counterfactual earnings) for workers displaced when aggregate unemployment exceeds 8% as those displaced when unemployment is below 5%.

	PDV of avg loss	
	As multiple of pre-displ. yearly earnings	As % of counterfactual earnings
All	1.71	11.9
Expansion	1.59	11.0
Recession	2.50	18.6
Unemployment rate		
$< 5.0\%$	1.06	9.9
$5.0 - 5.9\%$	1.56	10.9
$6.0 - 6.9\%$	1.58	10.7
$7.0 - 7.9\%$	2.07	14.4
$\geqq 8.0\%$	2.82	19.8

The second key evidence is the level and, more importantly, cyclicality of job displacement from the Displaced Worker Supplement from CPS documented in Figure 1 as well as "layoffs and discharges" from JOLTS.

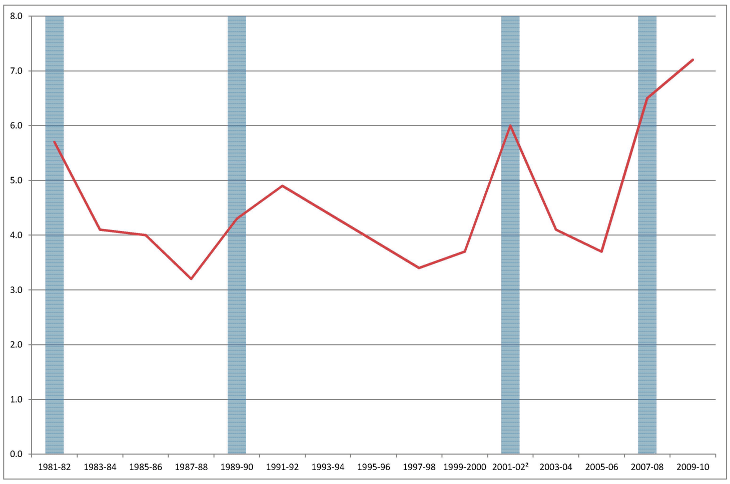

Figure 1. Displacement frequency according to the Displaced Worker Survey from CPS. 2-year periods.

A related measure is reported by Fujita and Ramey (2012). They compute that the correlation between the employment-to-unemployment transition rate and labor productivity is -0.52.

In summary, the key aspect to note here is that movement from employment to unemployment and its subcomponents displacements and layoffs are countercyclical. We also note that they spike early in recessions.

3 Model

The basic building blocks of our model is similar to Lise and Robin (2014), henceforth LR.[3] In terms of human capital dynamics the model is in the tradition of Ljungqvist and Sargent (1998). We include heterogeneity both on the worker and the firm side. Worker human capital is indexed by x and the match type is indexed by y. Output from a match is $p(x, y, z)$ where z denotes aggregate TFP and $\pi(z, z')$ denotes the Markov transition probability of z. There is no capital stock. Workers search for jobs both when employed and unemployed. Utility is linear and discounted by a factor β for both workers and firms. Wages are determined by Bertrand competition between firms so that a worker always receive a value equal to his outside option.

Both x and y follow stochastic processes. Let the Markov transition probability $\pi_y(y, y')$ denote the dynamics of the match-specific productivity and let $\pi_{xe}(x, x')$ $(\pi_{xu}(x, x'))$ denote the Markov

[3] Compared to LR the features we add are i) Accumulation of human capital , x, on-the-job as well as decumulation during unemployment, and ii) idiosyncratic shocks to the match-specific productivity y to generate empirically relevant earnings losses following endogenous separations. Another difference from LR is that the quality y of a match is not known when a vacancy is posted. This last difference is due to our need to compute individual wages (earnings), which LR did not do.

transition probability for the worker's human capital level while employed (unemployed). Human capital of employed workers is weakly increasing while for unemployed workers it is weakly decreasing.

Let us here mention two computational aspects of the model. First, Bertrand wage determination jointly with the common discount factor that follows from linear utility implies that the surplus of a match becomes independent of the cross-sectional distributions of workers and firms. This was pointed out by LR and simplifies computations significantly. In particular, equilibrium allocations can be solved for without computing the expected next period distribution of workers across firms and within the pool of unemployed. Second, computing individual wages (or to be correct, earnings) and value functions for workers are still non-trivial tasks. The challenge is that current wages depend on the probability of receiving a job offer the next period. In turn this depends on future labor market tightness. A key determinant for tightness is the expected value to a firm of matching with a worker in the future, which in turn depends on the distribution of workers with different abilities across firms with different productivity and within the unemployment pool. Fortunately, the equilibrium conditions of our model indicate three moments that well capture this large dimensional object. We then use a Krusell and Smith (1998) style algorithm to let these three moments summarize and predict the labor market tightness, thereby enabling us to solve for the wages. For details on the solution algorithm see section A.2 below.

3.1 Labor market flows - separations into unemployment and preliminaries

Let us start by providing an overview of the timing protocol. The sequence of events within a period are the following: First, the aggregate productivity shock z and the idiosyncratic shocks (x, y) are realized. Second, separations into unemployment occur. Then firms post vacancies and workers search. Finally, new matches are formed, wages are set and production takes place.

Let $\mathbf{1}\{\}$ denote the indicator function and let $S(x, y, z)$ denote the total surplus of a match. Matches with negative total surplus $S(x, y, z)$ are endogenously dissolved. In addition, a fraction δ of matches are exogenously destroyed every period.

The stock of unemployed after endogenous and exogenous separations into unemployment is:

$$u_+(x,z) = \sum_{x_{-1}} \pi_{xu}(x_{-1},x)\,u(x_{-1},z_{-1}) + \sum_{x_{-1}}\sum_{y_{-1}} \left(\mathbf{1}\{S(x,y,z)<0\} + \delta\mathbf{1}\{S(x,y,z)\geq 0\}\right)\pi_{xe}(x_{-1},x)\,\pi_y(y_{-1},y)\,h(x_{-1},y_{-1},z_{-1}). \tag{1}$$

The stock of matches of type (x, y) at this point is:

$$h_{+}(x,y,z) = \sum_{x_{-1}} \sum_{y_{-1}} (1-\delta) \mathbf{1}\{S(x,y,z) \geq 0\} \pi_{xe}(x_{-1}, x) \pi_{y}(y_{-1}, y) h(x_{-1}, y_{-1}, z_{-1}). \quad (2)$$

After separations into unemployment, firms post vacancies and workers search. An unemployed worker exerts search effort s_o and an employed worker exerts search effort s_1. The aggregate amount of search effort is accordingly:

$$L_t \equiv s_o \sum_{x \in X} u_{+}(x,z) + s_1 \sum_{x \in X} \sum_{y \in Y} h_{+}(x,y,z). \quad (3)$$

where X is the set of human capital states and Y the set of match-specific productivity states. We assume the following Cobb-Douglas meeting function:

$$M_t \equiv \min\left\{\alpha L_t^{\omega} V_t^{1-\omega}, L_t, V_t\right\}. \quad (4)$$

3.2 Total surplus and values of unemployment

A worker that is unemployed during the production phase receives a flow income of $b(x,z)$.[4] Due to the negotiation setup where employers reap the entire surplus above the worker's outside option, the value of unemployment, $B(x,z)$, is independent of the job finding probability, and any other endogenous variable or distribution:

$$B(x,z) = b(x,z) + \frac{1}{1+r} \sum_{z' \in Z} \sum_{x' \in X} B(x', z') \pi_{xu}(x, x') \pi(z, z') \quad . \quad (5)$$

where Z is the set of a aggregate productivity states. As shown by LR (their proposition 1 and the proof thereof), the total surplus of a match does not depend on any of the endogenous distributions. It is simply:

$$S(x,y,z) = p(x,y,z) - b(x) + \frac{1-\delta}{1+r} \sum_{z' \in Z} \sum_{x' \in X} \sum_{y' \in Y} \max\left\{S(x', y', z'), 0\right\} \pi_{xe}(x, x') \pi_{y}(y, y') \pi(z, z') \quad (6)$$

This surplus can also be written as the sum of worker and employer surplus:

$$S(x,y,z) = W(w,x,y,z;\Gamma) - B(x,z) + \Pi(w,x,y,z;\Gamma).$$

As mentioned above, we assume that firms have all the bargaining power. Accordingly, workers

[4] For the time being we actually assume that the flow income is independent of the aggregate state, $b(x,z) = b(x)$.

receive a value corresponding to their outside option. The expected value of a new match for a firm is

$$\begin{aligned} J_t &= \sum_{x\in X}\sum_{y\in Y}\frac{s_0}{L_t}u_+(x,z)\max\{S(x,y,z),0\}f(y) \qquad (7) \\ &+\sum_{x\in X}\sum_{y\in Y}\sum_{\tilde{y}\in Y}\frac{s_1}{L_t}h_+(x,\tilde{y},z)\max\{S(x,y,z)-S(x,\tilde{y},z),0\}f(y). \end{aligned}$$

where $f(y)$ is the pdf of the match-specific productivity. All firms face the same pdf. This implies that aggregation in terms of vacancy posting across firms is trivial, $v_t = V_t$. The first term in (7) refers to expected surplus from recruiting out of the pool of unemployed and the second term refers to surplus from recruitment from existing matches.

3.3 Vacancy determination

If a firm posts v_t vacancies it incurs a convex cost $c(v_t)$. The optimality condition for vacancy creation implies:

$$c'(v_t) = q_t J_t$$

where $q_t = M_t/V_t$ is the probability that a vacancy meets a worker.

We assume that the vacancy cost function has the following functional form:

$$c(v_t) = \frac{c_0 v_t^{1+c_1}}{1+c_1}.$$

Together with the matching function (4) and an assumption of an interior solution this implies that equilibrium vacancy postings are determined by

$$v_t = V_t = \left(\frac{\alpha J_t}{c_0\theta_t^{\omega}}\right)^{1/c_1} \qquad (8)$$

where $\theta_t \equiv \frac{V_t}{L_t}$.

By using eq. (8) and the definitions of θ_t and V_t one can derive aggregate labor market tightness as:

$$\theta_t = \left[\frac{1}{L_t}\left(\frac{\alpha J_t}{c_0}\right)^{1/c_1}\right]^{\frac{c_1}{c_1+\omega}}. \qquad (9)$$

3.4 New matches and the resulting distributional dynamics

For a new match to be formed two parts are required: the two parties must meet according to the meeting function (4) and the match must be an improvement over status quo (the current match or unemployment). The unemployment distribution $u(x,z)$ resulting from vacancy postings and search accordingly are:

$$u(x,z) = u_+(x,z)\left(1 - s_0 \frac{M_t}{L_t} \sum_y \mathbf{1}\{S(x,y,z) \geq 0\} f(y)\right). \tag{10}$$

The corresponding expression for the employment distribution $h(x,y,z)$ is:

$$\begin{aligned} h(x,y,z) \quad = \quad & h_+(x,y,z) + \underbrace{u_+(x,z) f(y) s_0 \frac{M_t}{L_t} \mathbf{1}\{S(x,y,z) \geq 0\}}_{\text{mass hired from unemployment}} \\ & \underbrace{-h_+(x,y,z) s_1 \frac{M_t}{L_t} \sum_{\tilde{y}} f(\tilde{y}) \mathbf{1}\{S(x,\tilde{y},z) > S(x,y,z)\}}_{\text{mass lost to more productive matches}} \\ & \underbrace{+s_1 \frac{M_t}{L_t} \sum_{\tilde{y}} h_+(x,\tilde{y},z) \mathbf{1}\{S(x,y,z) > S(x,\tilde{y},z)\} f(y)}_{\text{mass poached from less productive matches}} \end{aligned} \tag{11}$$

where $\tilde{y}$ denotes the competing match (job type).

3.5 Wage determination

As already mentioned, we denote the present value to a worker with human capital x, in a match with quality y with wage w and aggregate productivity z by $W(w,x,y,z)$. Making use of $q_{t+1} = M_{t+1}/V_{t+1}$ and $M_t \equiv \alpha L_t^{\omega} V_t^{1-\omega}$, we can rewrite the probability of meeting a firm for an employed worker the following way:

$$\lambda_{1,t+1} \frac{q_{t+1} V_{t+1}}{M_{t+1}} = s_1 \alpha \theta_{t+1}^{1-\omega}.$$

Given the wage w, the worker value is, summarizing the endogenous aggregate state as $\Gamma \equiv (h_+, u_+)$:

$$\begin{aligned} W(w,x,y,z;\Gamma) \quad = \quad & w + \frac{1}{1+r} \sum_{z'} \sum_{x'} \sum_{y'} \pi_y(y,y') \pi(z,z') \left\{\mathbf{1}\left\{S(x',y',z') < 0\right\} + \delta \mathbf{1}\left\{S(x',y',z') \geq 0\right\}\right. \\ & \times \pi_{xu}(x,x') B(x',z') + \pi_{xe}(x,x') (1-\delta) \mathbf{1}\left\{S(x',y',z') \geq 0\right\} \left[s_1 \alpha \theta^{1-\omega}\right. \\ & \times \left(S(x',y',z') + B(x',z')\right) \sum_{\tilde{y}} \mathbf{1}\left\{S(x',\tilde{y},z') > S(x',y,z')\right\} f(\tilde{y}) \\ & + s_1 \alpha \theta^{1-\omega} \sum_{\tilde{y}} \left(S(x',\tilde{y},z') + B(x',z')\right) \mathbf{1}\left\{S(x',\tilde{y},z') \leq S(x',y',z')\right\} f(\tilde{y}) \\ & \left.\left. + \left(1 - s_1 \alpha \theta^{1-\omega}\right) \min\left\{S(x',y',z') + B(x',z'), \max\left\{W(w,x',y',z';\Gamma'), B(x',z')\right\}\right\}\right]\right\} \end{aligned} \tag{12}$$

Denote the renegotiated wage by w'. Workers hired out of unemployment receive their reservation wage $w' = \phi_0(x,y,z;\Gamma)$ such that

$$W(w',x,y,z;\Gamma) = B(x,z).$$

For employed workers that have received a poaching offer, Bertrand competition between employers imply that these workers have a present value $W(w,x,y,z;\Gamma)$ equal to the total surplus of the second best match that they have encountered. If a worker of type x, employed at a firm of type y is poached by a firm of type $\tilde{y}$ then, if $S(x,y,z) < S(x,\tilde{y},z)$ the worker switches to the new match and gets the wage $w' = \phi_1(x,\tilde{y},y,z;\Gamma)$ satisfying

$$W\left(w',x,\tilde{y},z;\Gamma\right) = S(x,y,z) + B(x,z). \tag{13}$$

If instead $S(x,y,z) \geq S(x,\tilde{y},z)$ the worker remains in his current match and gets the maximum of the value of the outside match $(x,\tilde{y})$ and the value at the current wage

$$W\left(w',x,y,z;\Gamma\right) = \max\left\{S(x,\tilde{y},z) + B(x,z), W(w,x,y,z;\Gamma)\right\}, \tag{14}$$

Here, when $S(x,\tilde{y},z)+B(x,z) \geq W(w,x,y,z)$ we define $w' = \phi_1(x,y,\tilde{y},z;\Gamma)$ satisfying $W(w',x,y,z;\Gamma) = S(x,\tilde{y},z) + B(x,z)$.

Even wages for workers that do not receive poaching offers can be rebargained, as aggregate or idiosyncratic shocks might affect whether the current wage is in the bargaining set, i.e.,

$$B(x,z) \leqslant W(w,x,y,z;\Gamma) \leqslant S(x,y,z) + B(x,z). \tag{15}$$

Along the lines of Hall (2005), the wage w is fixed within a match as long as it is in the bargaining set (15). Letting $\phi_2(w,x,y,z;\Gamma)$ denote the wage in case employed workers do not get poaching offers, then, if the wage is in the bargaining set so that (15) holds, we have $\phi_2(w,x,y,z;\Gamma) = w$. In case the wage is too low or too high, violating (15), then

$$\begin{aligned} &\text{if } W(w,x,y,z;\Gamma) < B(x,z) \text{ then } w' = \phi_2(w,x,y,z;\Gamma) = \phi_0(x,y,z;\Gamma) \\ &\text{is set such that } W\left(w',x,y,z;\Gamma\right) = B(x,z) \end{aligned} \tag{16}$$

and

$$\begin{aligned} &\text{if } W(w,x,y,z;\Gamma) > S(x,y,z) + B(x,z) \text{ then } w' = \phi_2(w,x,y,z;\Gamma) = \phi_1(x,y,y,z;\Gamma) \\ &\text{is set such that } W\left(w',x,y,z;\Gamma\right) = S(x,y,z) + B(x,z). \end{aligned} \tag{17}$$

3.6 Wage distribution

When determining the wage distribution, the current wage of the worker is a state variable. It summarizes the entire wage-relevant history of the worker. Conditional on aggregate technology evolving from z_{-1} to z, the distribution of matches over w, x, y and z evolves according to

$$h_{+}^{so}(w,x,y,z)=\sum_{x_{-1}}\sum_{y_{-1}}(1-\delta)\,\mathbf{1}\{S(x,y,z)\geq 0\}\,\pi_{xe}(x_{-1},x)\,\pi_{y}(y_{-1},y)\,h^{so}(w,x_{-1},y_{-1},z_{-1})\,. \quad (18)$$

due to separations and idiosyncratic shocks. Analogously to section 3.4, we define $h^{so}(w,x,y,z)$ which accounts for new matches; see Appendix A.1.

3.6.1 Earning loss when displaced

To compute earnings losses in booms and recessions, respectively, we first need to define what constitutes a boom and a recession. In the model we define a time period, i.e. a month, as a boom (recession) if GDP is above (below) the 12th percentile in the simulated output of our model. The choice of the 12th percentile as the cutoff between boom and recession is made to enable comparison with DvW. They use NBER dated recessions and these make up 12% of their sample period.

The observation frequency of earnings in the empirical literature is annual. We accordingly compute earnings losses of workers displaced in a particular calender year. We further follow DvW in that when we compute earnings losses we weight each boom (or recession) year by the number of months of that year that the economy was in a boom (recession). For workers displaced in a given boom (recession) month, we then compute average income for displaced (defined as separated, either endogenously or exogenously) and non-displaced workers, respectively, over the earnings loss horizon. We let the non-displaced workers be identical to the displaced workers in terms of all individual state variables, w, x, y, in the period prior to displacement. In this way we minimize the selection effects in generating earnings losses.[5,6]

4 Calibration

The production function takes the form $p(x,y,z) = xyz$. Unemployment benefits are $b(x,z) = b_0 + b_1 x$. The initial match productivity $f(y)$ is beta distributed. The transition matrices $\pi_{xe}(x,x')$

[5] Note that, given that we know how to compute transitions using the equations for $u_{+}(x_{-1},z_{-1})$, $u(x,z)$, $h_{+}^{so}(w,x_{-1},y_{-1},z_{-1})$ and $h^{so}(w,x,y,z)$, we can feed in an arbitrary initial worker distribution and follow how the distribution of these workers evolve over time. Then, we can use the resulting distributions to compute earnings in the two groups.

[6] As in the empirical literature, e.g. DvW, we require that non-displaced workers stay with the same employer for the first 3 years after the displacement date. This requirement slightly modifies the expressions for $h_{+}^{so}(w,x_{-1},y_{-1},z_{-1})$ and $h^{so}(w,x,y,z)$.

and $\pi_{xu}(x, x')$ for human capital are defined as follows. For employed workers:

$$
\begin{aligned}
x' &= x + stepsize \text{ with probability } x_{up} \\
x &= x \qquad\quad \text{ with probability } (1 - x_{up})
\end{aligned}
$$

and for unemployed workers:

$$
\begin{aligned}
x' &= x - stepsize \text{ with probability } x_{dn} \\
x &= x \qquad\quad \text{ with probability } (1 - x_{dn})
\end{aligned}
$$

As mentioned above, the frequency of the model is monthly. The calibration is very preliminary and is documented in Table 2.

Table 2: Baseline Calibration of the Model

	Explanation	Value	Source
α	Matching function productivity	0.155	Matching avg unemployment rate
ω	Matching function elasticity	0.5	Literature
δ	Exogenous match separation rate	0.02	LR
s_1/s_0	Search intensity employed	0.173	LR
c_0	Level vacancy cost	0.02	
c_1	Curvature vacancy cost	1.066	LR
σ	TFP shock std dev	0.0017	GDP volatility, Cooley
ρ	TFP shock persistence	0.983	$= 0.95^{1/3}$, Cooley
σ_y	Match-specific shock std.dev.	0.04	
ρ_y	Match-specific shock persistence	0.92	
x_{up}	Human capital gain, probability	0.015	
r	Interest rate	0.0041	$0.05^{1/12}$, LR/literature
b_0	Unempl. benefit intercept	0.0175	
b_1	Unempl. benefit coefficient on x	0.5106	$\bar{b}/\bar{w} \approx 0.9$

Note that the human capital gain parameter x_{up} is currently set in an undisciplined way. Its counterpart x_{dn} is set equal to $x_{up}\frac{e}{u}$ to minimize aggregate drift. Nevertheless, the implied human capital loss during unemployment is moderate as the value of x_{dn} and the grid over human capital x jointly imply an expected human capital loss of roughly 3% per month.

4.1 Intended calibration approach

We intend to (but have not yet finished the computations required) calibrate the model in the following way: Parameters whose values are well established in the literature or from solid empirics are set outside the model. Table 3 document these parameter values and their sources.

The parameter value of σ_{y-init} from Syverson (2004) needs some explanation. Syverson reports

Table 3: Parameters set outside model

	Explanation	Value	Source
ω	Matching function elasticity	0.5	Literature
δ	Exogenous match separation rate	0.0187	Average quits in JOLTS
c_1	Vacancy cost curvature	1	Quadratic cost
σ	TFP shock std.dev.	0.007838	Hagedorn-Manovskii
ρ	TFP shock persistence	$0.765^{1/3} = 0.915$	Hagedorn-Manovskii
σ_y	Match-specific shock std.dev.	0.13	Foster-Haltiwanger-Syverson
ρ_y	Match-specific shock persistence	0.79	Foster-Haltiwanger-Syverson
σ_{y-init}	Std.dev. initial match quality	0.1428	Syverson
r	Interest rate	0.0041	$0.05^{1/12}$, LR/literature

the within-sector inter-quartile ratio (p25/p75) of firm productivity of 0.662. We pick the standard deviation of the beta distribution that matches this inter-quartile ratio for the productivity of new matches.

Many parameters of this model do not have well established values and will instead be calibrated jointly to match key moments. In particular, we match the moments in Table 4 by minimizing the squared percentage deviation between model and data moments.

Table 4: Moments to Match in Calibration of the Model

Moment	Data source	Target value	Model value [**TBD**]
U2E transition rate, mean	Shimer (2005)	0.45	
J2J transition rate, mean	Moscarini-Thompson	0.032	
E2U transition rate, mean	Hagedorn-Manovskii	0.026	
Corr(E2U transition,labor prod)	Fujita-Ramey	-0.52	
Unemployment, mean	BLS 1980-2011	6.4%	
Unemployment, std.dev	BLS 1980-2011	1.65%	
GDP volatility (std.dev)	Cooley	1.72%	
GDP persistence	Cooley	0.85	
Earnings loss, recession 1st year	DvW	39%	
Earnings loss, boom 1st year	DvW	25%	
Wage disp: Variance log wage	Lise-Meghir-Robin	0.31	

The relevant measure of wage dispersion for our model is "residual" wage dispersion, i.e. controlling for heterogeneity not present in the model such as age, education, etc. Lise, Meghir and Robin (2015) provide one such measure using NLSY 1979 data.[7] A similar value for residual wage dispersion is reported by Heathcote, Perri and Violante (2010). The above moment matching determines the 6 parameters in Table 5.

We always keep $x_{dn} = x_{up} \frac{e}{u}$ to minimize aggregate drift (bunching at end-point) in human capital. In terms of numerical details, we use Adda and Cooper's (2003) discretization of AR(1) processes

[7] To be specific, they report (their Table 4) wage dispersion for eight different groups (two education groups and four age groups) and we take the average of these eight different values.

Table 5: Parameters obtained by moment-matching

Parameter	Explanation	Value
α	Matching function productivity	
s_1/s_0	Relative search intensity of employed	
c_0	Vacancy cost level	
x_{up}	Human capital gain, probability	
b_0	Unemployment benefit intercept	
b_1	Unemployment benefit coefficient on x	

which has equal unconditional probability of visiting each node and has been proven to be accurate for processes with high persistence. The number of gridpoints for x, y and z are 8, 5 and 3 respectively. The wage grid contains 15 points.

5 Preliminary results

Below are the main results for the very preliminary calibration.

The model results for earnings loss for displaced workers relative to non-displaced as a percent of pre-displacement earnings are documented in Figure 2. Note that only earnings losses for the first year after displacement has been targeted in the calibration. For comparison we reproduce DvW's empirical results in Figure 3.

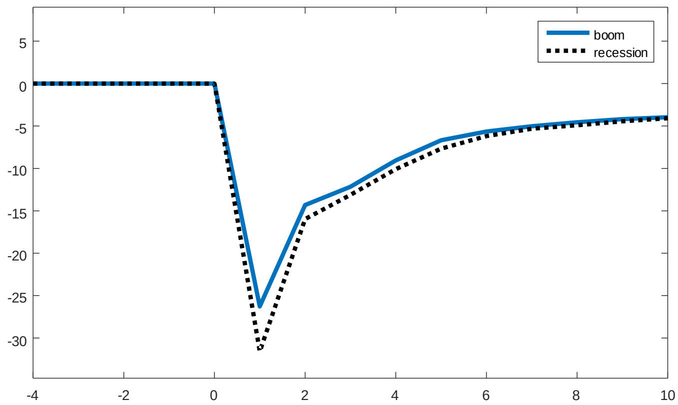

Figure 2. Average earnings loss of displaced workers relative to non-displaced as a percent of pre-displacement earnings.

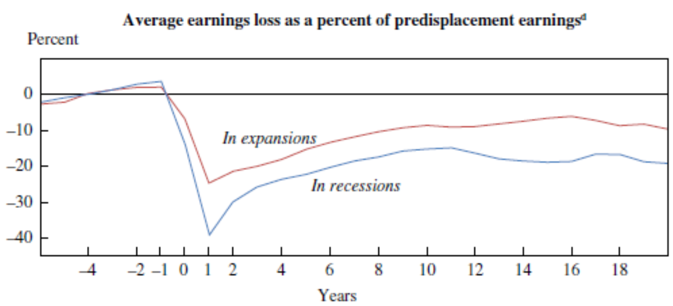

Figure 3. Empirical earnings loss results from Davis and von Wachter (2011).

The level of earnings losses in the model is roughly in line with the empirics. The difference between boom and recession is lower and less persistent in the model.

Other non-targeted relevant moments implied by the model are presented in Table 6.

Table 6: Moments of Model

Variable	Data	Model
Unemployment without bus. cycles	n/a	0.050
Unemployment in the simulation	0.064	0.060
Correlation(Unemp, GDP)		-0.90

5.1 Welfare costs of business cycle results

As outlined above we turn off aggregate shocks so as to be able to compute the welfare costs of business cycles. In particular, we quantify the effect of business cycles on GDP and employment. We find that in our model the presence of aggregate shocks reduce GDP (employment) by 1.5% (1.1%). This is a large effect on GDP, roughly in line with the extra earning losses of workers induced by cycles according to the simple model-free computation. We note that the effect goes through both human capital and the employment level. But the key force is the human capital dynamics. When we turn off the human capital dynamics in our model the GDP losses from business cycles are negligible.

6 Conclusions

A central question in macroeconomics is whether the welfare costs of business cycles are large or not. Since Lucas (1987) it has been well established that, for conventional calibrations, the cost of aggregate consumption fluctuations is very small. We analyze a previously unexplored channel where cyclical variation in the unemployment rate reduces the aggregate level of output and welfare. Our mechanism concerns the earnings losses generated by job displacement (mass layoffs). Empirical evidence point to that this type of earnings losses are large. Furthermore, both job displacement frequency and earnings losses per displaced worker are increasing in the unemployment rate. These two facts imply that displacement occurs at a higher frequency in times when it is more costly implying that aggregate earnings losses are convex in the unemployment rate. An economy with the same average displacement rate but without any unemployment volatility would yield lower earnings losses due to displacement.

We model the above phenomenon in a general equilibrium framework with a search and matching labor market. The two key facts mentioned above drive the key mechanism in our model and therefore need to be captured well. To generate the first fact, the countercyclicality of job displacement, is straight forward and achieved by modelling endogenous separations of jobs. The second fact, that earnings losses per displaced worker are increasing in the unemployment rate, follows from longer unemployment spells and lower job-to-job transitions in recessions and is amplified by human capital loss during unemployment. Our model accounts for heterogeneity on both the firm and worker side. Both unemployed and employed workers search for jobs, i.e. we allow for on-the-job search.

We find that the welfare losses of business cycles are non-negligible. In our preliminary calibration, output losses amount to 1.5 percent of GDP.

A Appendix

A.1 Employment transitions

When accounting for the wage distribution, the employment transition follows

$$
\begin{aligned}
& h^{so}\left(w^{*},x,y,z\right)= \\
& h_{+}^{so}\left(w^{*},x,y,z\right)-\underbrace{h_{+}^{so}\left(w^{*},x,y,z\right)\lambda_{1,t}\int f\left(\tilde{y}\right)S_{\tilde{y}\geq y}\left(x,z\right)d\tilde{y}}_{\text{mass lost to more productive matches}} \\
& \underbrace{-h_{+}^{so}\left(w^{*},x,y,z\right)\lambda_{1,t}\sum_{\tilde{y}}\mathbf{1}\left\{S\left(x,\tilde{y},z\right)+B\left(x,z\right)>W\left(w^{*},x,y,z;\Gamma\right)\right\}f\left(\tilde{y}\right)S_{y\geq\tilde{y}}\left(x,z\right)}_{\text{mass lost to higher wage offers from less productive matches}} \\
& \underbrace{+\lambda_{1,t}\sum_{\tilde{y}}\sum_{\tilde{w}}h_{+}^{so}\left(\tilde{w},x,y,z\right)\mathbf{1}\left\{w\left(\tilde{w},x,y,z;\Gamma\right)=w^{*}\right\}f\left(\tilde{y}\right)S_{y\geq\tilde{y}}\left(x,z\right)}_{\text{mass gained from increased wage due to offers from less productive matches}} \\
& \underbrace{+\lambda_{1,t}f\left(y\right)\sum_{\tilde{y}}h_{+}\left(x,\tilde{y}\right)\mathbf{1}\left\{W\left(w^{*},x,y,z;\Gamma\right)=S\left(x,\tilde{y},z\right)+B\left(x,z\right)\right\}S_{y\geq\tilde{y}}\left(x,z\right)}_{\text{mass poached from less productive matches}} \\
& \underbrace{-h_{+}^{so}\left(w^{*},x,y,z\right)\mathbf{1}\left\{W\left(w^{*},x,y,z;\Gamma\right)\notin BS\left(x,y,z\right)\right\}}_{\text{mass lost due to being outside bargaining set}} \\
& \underbrace{+\sum_{\tilde{w}}h_{+}^{so}\left(\tilde{w},x,y,z\right)\mathbf{1}\left\{w\left(\tilde{w},x,y,z;\Gamma\right)=w^{*}\right\}\mathbf{1}\left\{W\left(\tilde{w},x,y,z;\Gamma\right)\notin BS\left(x,y,z\right)\right\}}_{\text{mass gained from other wages being outside bargaining set}} \\
& \underbrace{+\lambda_{0,t}u_{t+}\left(x\right)f\left(y\right)S_{xyz}\mathbf{1}\left\{W\left(w^{*},x,y,z;\Gamma\right)=B\left(x,z\right)\right\}}_{\text{mass hired from unemployment}}
\end{aligned}
\tag{19}
$$

where

$$
\begin{aligned}
BS\left(x,y,z\right) &= \left[B\left(x,z\right),S\left(x,y,z\right)+B\left(x,z\right)\right] \\
\lambda_{1,t} &= s_{1}M_{t+1}/L_{t+1} \\
S_{xyz} &\equiv \mathbf{1}\left\{S\left(x,y,z\right)\geq 0\right\} \\
S_{y\geq\tilde{y}}\left(x,z\right) &\equiv \mathbf{1}\left\{S\left(x,y,z\right)\geq S\left(x,\tilde{y},z\right)\right\} \\
S_{\tilde{y}\geq y}\left(x,z\right) &\equiv \mathbf{1}\left\{S\left(x,\tilde{y},z\right)\geq S\left(x,y,z\right)\right\} \\
S_{y>\tilde{y}}\left(x,z\right) &\equiv \mathbf{1}\left\{S\left(x,y,z\right)>S\left(x,\tilde{y},z\right)\right\} \\
S_{\tilde{y}>y}\left(x,z\right) &\equiv \mathbf{1}\left\{S\left(x,\tilde{y},z\right)>S\left(x,y,z\right)\right\}
\end{aligned}
$$

A.2 Solution algorithm

Step 1. Value function iteration to solve for $S(x,y,z)$ in (6) and $B(x,z)$ in (5).

Step 2. Solve for $\{J_t, h_{t+1}, u_{t+1}, V_t, L_t, M_t, \Gamma_t\}_{t=0}^{T}$ recursively for each time period. Given the solution for $S(x, y, z)$, the initial conditions u_0 and h_0, and a sequence for $\{z_t\}_{t=0...T}$, we iterate forward on the following to create a time series for u_t, h_t and any aggregates of these we are interested in:

i) calculate $u_{t+}(x)$ and $h_{t+}(x, y)$ using (1) and (2)

ii) calculate L_t by aggregating over $u_{t+}(x)$ and $h_{t+}(x, y)$

iii) calculate J_t using (7). Note that we can replace $\lambda_{0,t}/M_t$ with $s_{0,t}/L_t$ and $\lambda_{1,t}/M_t$ with $s_{1,t}/L_t$, so this is all known.

iv) calculate θ_t using (9)

v) calculate V_t using (8)

vi) calculate $u_{t+1}(x)$ and $h_{t+1}(x, y)$ using (10) and employment transition (11)

To obtain the ergodic distributions for $u_{t+1}(x)$ and $h_{t+1}(x, y)$ simulate above for a fixed z until convergence in these distributions.

Given the sequence based on $\{z_t\}_{t=0...T}$ above, we use the resulting sequence of θ to compute wages and then the sequence of h_{t+1}^{so} to compute relevant moments of the wage distribution along the sequence where we have followed the algorithm described in section A.2.1 to compute worker values $W(w, x, y, z; \Gamma)$ and wages $w(w, x, y, z; \Gamma)$.

A.2.1 Algorithm for determination of W and w

As can be seen from (12) the worker value function depends on Γ', i.e. the entire expected next period distribution of matches across x and y and unemployed workers distribution over x. The challenge is to reduce the full dimensionality of the distributions Γ' to something manageable. The key to our algorithm is to note that all influence of the endogenous distributions goes through the next period labor market tightness, θ'. In addition, according to (9) labor market tightness is a function only of (3) and (7). Hence, we can write θ as a function of the moments that make up (3) and (7); $\theta = \Theta(m_1, m_2, m_3; z)$. In particular, based on (3),

$$m_1 = \sum_x u_+(x, z)$$

as we note that $\sum_x \sum_y h_+(x, y, z) = 1 - \sum_x u_+(x, z)$ and accordingly $L_t \equiv s_o \sum_x u_+(x, z) + s_1 (1 - \sum_x u_+(x, z))$. Given L_t from m_1, equation (7) implies that J is fully determined by the following to terms:

$$m_2 = \sum_x \sum_y u_+(x, z) \max\{S(x, y, z), 0\} f(y)$$

and

$$m_3 = \sum_x \sum_y \sum_{\tilde{y}} h_+ (x, \tilde{y}, z) \max \{S (x, y, z) - S (x, \tilde{y}, z), 0\} f (y).$$

To compute next period values of these moments we assume a linear relationship to today's moments. Thus, we write

$$m'_m = H_m (m_1, m_2, m_3, z')$$

We loosely follow Krusell and Smith (1998). Since we can compute the evolution of the distributions u_+ and h_+ and θ without solving for wages and values, we generate a sequence of aggregate productivity shocks, compute m_i and tightness θ and, given a linear functional form of H_m and Θ, then estimate the functions H_m and Θ. Given the above arguments it is unsurprising that the R^2 of the function $\Theta (m_1, m_2, m_3)$ is approximately unity (> 0.98). It turns out that $H_m (m_1, m_2, m_3, z')$ also has a reasonably high R^2.

In the end, we can replace the distributions in Γ' by (m_1, m_2, m_3) so that instead of $(w, x, y, z; \Gamma)$ the final state vector is $(w, x, y, z; m_1, m_2, m_3)$. With the functions Θ and H_m at hand, we solve for worker values W. This is done with value function iteration. This method is facilitated by a good initial guess obtained by noting that, abstracting from future shocks, the worker value function W is piecewise linear in the wage with two kinks. The wage interval between the kinks correspond to the bargaining set. Below the lowest kink, and above the highest, the slope is unity as the future wage is independent of the current wage.

Finally, once we know the worker values W we can solve for wages w residually. This amounts to rewriting equation (12) to find the wage that yields the right value of W for the current state vector $(w, x, y, z; m_1, m_2, m_3)$ given the expected future values for the worker.

B References

Adda, Jerome and Russell Cooper, 2003, Dynamic Economics, MIT Press.

Burdett, K., C. Carrillo-Tudela and M. Coles, 2015, "The Cost of Job Loss", mimeo.

Davis, S. and T. von Wachter, 2011, "Recessions and the Costs of Job Loss," Brookings Papers on Economic Activity, Fall(1), pp 1-72.

Den Haan, W.J., and P. Sedlacek, 2014, "Inefficient Continuation Decisions, Job Creation Costs, and the Cost of Business Cycles," Quantitative Economics, Vol. 5(2), pp 297–349.

Farber, Henry, 2005, "What Do We Know about Job Loss in the United States? Evidence from the Displaced Workers Survey, 1984–2004", mimeo.

Foster, Lucia, John Haltiwanger and Chad Syverson, "Reallocation, Firm Turnover, and Efficiency: Selection on Productivity or Profitability?," American Economic Review 2008, Vol. 98(1), pp 394–425.

Fujita, Shigeru and Garey Ramey, "Exogenous versus Endogenous Separation", American Economic Journal: Macro, 2012, Vol. 4(4), pp 68-93.

Imrohoroğlu, Ayşe, 1989, "Cost of Business Cycles with Indivisibilities and Liquidity Constraints," Journal of Political Economy, Vol. 97(6), pp 1364-1383.

Jacobson, Louis, Robert LaLonde, and Daniel Sullivan, 1993. "Earnings Losses of Displaced Workers." American Economic Review, Vol. 83(4), pp 685–709.

Jarosch, Gregor, 2014, "Falling off the Ladder - Earnings Losses from Job Loss", mimeo.

Jung, P. and M. Kuhn, 2014, "Earnings losses and labor mobility over the lifecycle", mimeo.

Hall, Robert E. 2005. "Employment Fluctuations with Equilibrium Wage Stickiness." American Economic Review, Vol. 95(1), pp 50-65.

Hassan, Tarek, and Thomas Mertens, 2014, "The Social Cost of Near-Rational Investment", mimeo.

Huckfeldt, Christopher, 2014, "The Scarring Effect of Recessions: A Quantitative Analysis", mimeo.

Krebs, Tom, 2003, "Growth and welfare effects of business cycles in economies with idiosyncratic human capital risk", Review of Economic Dynamics, Vol. 6, pp 846–868.

Krebs, Tom, 2007, "Job Displacement Risk and the Cost of Business Cycles," American Economic Review, Vol. 97, pp 664–686.

Krolikowski, Pavel, 2014, "Job Ladders and Earnings of Displaced Workers", mimeo.

Lise, Jeremy and Jean-Marc Robin, 2014, "The Macro-dynamics of Sorting between Workers and Firms", mimeo.

Ljungqvist, Lars and Thomas Sargent, 1998, "The European Unemployment Dilemma", Journal of Political Economy, Vol 106.

Lucas, Robert E. Jr., 1987, “Models of Business Cycles”, New York: Blackwell.

Syverson, Chad, 2004, “Product Substitutability and Productivity Dispersion,” Review of Economics and Statistics, Vol 86(2), pp 534–550.