Lumpy Capital, Labor Market Search and Employment Dynamics over Business Cycles

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Abstract

This paper incorporates labor search frictions into a model with lumpy capital to explain a set of stylized facts about the United States labor market dynamics over business cycles. All of these facts are related to firm size: (1) job creation is procyclical in both small and large firms; (2) job destruction is countercyclical in large firms, but, paradoxically, it is procyclical in small firms; and (3) job creation and job destruction are more volatile in large firms than in small firms. The model is calibrated to US data and its predictions are broadly consistent with the facts. The success of the model relies on the interaction between labor search and lumpy capital. Search frictions imply that even if two firms have the same history of investment, their employment levels can still differ depending on their histories of labor market search outcome. In fact, a smaller size is the result of a firm's lack of success in hiring the desired amount of workers. Since capital and labor are complementary, a higher level of aggregate productivity increases the marginal productivity of capital by more in a large firm than in a a small firm, conditioning on undertaking lumpy investment. As a result, investment rate increases are stronger in large firms than in small firms. In addition, as the labor market becomes tighter during booms, small firms' incentives to invest are further reduced. To complement the increased capital in large firms, workers migrate from small to large firms. Thus, job destruction in small firms may increase during booms.

Keywords: labor market search, lumpy capital, business cycle, job creation, job destruction

JEL Classification: E22 E24 E32 E37

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1 Introduction

In this paper I incorporate labor search frictions into a model with lumpy capital to explain a set of stylized facts about the United States labor market dynamics over business cycles. All of these facts are related to firm size, as defined by the number of employees in the firm. These empirical regularities are as follows: (1) job creation is procyclical in both small and large firms; (2) job destruction is countercyclical in large firms, but, paradoxically, it is procyclical in small firms; and (3) job creation and job destruction are more volatile in large firms than in small firms.

A full understanding of employment dynamics requires that we account for these facts. And, given the large share of national income represented by labor, the above facts are also important for a proper understanding of business cycles. Yet, standard models find it difficult to explain these facts. In a standard real business cycle model, for example, the size of a firm is not determinate. To account for firm sizes, the literature has introduced a fixed cost of investment (see Khan and Thomas 2003, and Lucas 1967). Such an extended model can explain why small and large firms have different volatility in investment and, therefore, in job creation and job destruction. However, such a model is not able to explain the puzzling fact (2) above, because it makes a firm's employment perfectly correlated with its capital stock.

To explain the above facts, I integrate labor search frictions with lumpy capital. The motivation behind modeling labor market search frictions and capital adjustment costs together is consistent with the empirical evidence showing that capital and labor adjustments are not made simultaneously (see Contreras 2007). With labor search frictions, a firm's employment depends not only on the firm's capital stock, but also on the firm's history of matches in the labor market. Thus, there is a non-degenerate distribution of employment levels among firms that have the same capital stock. The interaction between labor search and lumpy capital provides a mechanism to account for the stylized facts listed above.

In the model firms receive idiosyncratic shocks to the fixed capital adjustment costs. A firm only invests if this fixed cost is relatively low; otherwise, the capital depreciates in the firm. This random capital adjustment cost can generate an investment pattern that is consistent with a well known regularity: investment stays inactive for a few periods when the capital adjustment cost is relatively high and it spikes when the capital adjustment cost becomes relatively low. The history of investment thus determines the marginal labor productivity in a firm and, therefore, its employment decision.

Introducing labor search frictions disentangles firms' employment dynamics from the dynamics of their capital stock. If the labor market is perfect competitive, a firm's size of employment will be perfectly correlated with its capital stock. Search frictions imply that even if two firms have the same history of investment, their employment levels can still be different, depending on the outcome of their labor search and matching. The resulting size differences, in turn, affect investment decisions.

The fact (2) implies that there is an asymmetry in how aggregate shocks affect small versus large firms. The key to solving this puzzle is to find a way in which a positive aggregate productivity shock can lower the relative marginal labor productivity in small firms, compared to large firms, since a relatively lower marginal labor productivity would induce small firms to destroy jobs.[1] Given the complementarity between capital and labor in production, a relatively lower investment rate in small firms could deliver that relatively lower marginal labor productivity.

I calibrate the model to United States data and compute the stochastic equilibrium. The model's predictions are broadly consistent with the facts listed above. The story is as follows. During booms, when aggregate productivity goes up, the investment in both small and large firms increases. However, the investment rate increases by a larger proportion. In the numerical experiment a 1% permanent positive productivity shock increases the investment hazard rate by 5% in small firms and by 14% in large firms. The assymmetric investment behavior in small and large firms is because the immediate profit of investment in large firms increases by more in the presence of labor market frictions. Small firms may not be able to hire enough workers quickly to complement the lumpy investment, while large firms have a large pool of current workers who can operate the new capital

[1]Exit is an extreme case. Firms have zero marginal labor productivity after they exit. If exit rate increased by more in small firms than in large firms during booms, this could explain increased job destruction in small firms. However, during booms, job destruction from shutdown increases by more in large firms, as shown in Schuh and Triest (1998). See section 2 for details.

right after investing. In addition, labor market search frictions also affect investment decisions through labor market tightness. During booms, as firms multiply their vacancies to complement their increased investment, the labor market becomes tighter. This further reduces the small firms' incentives to invest, since a relatively stringent constraint on their future employment level lowers the profit margin of their investment. As investment increases relatively more in large firms, the relative marginal labor productivity in small firms decreases, and workers migrate from small firms to large firms. This is how job destruction in small firms may increase during booms.

The facts this paper seeks to explain were documented by Davis and Haltiwanger (1992) using U.S. manufacturing data. More recently, Moscarini and Postel-Vinay (2008) reported that both the employer to employer flow rate of workers and wages increase rapidly late in the expansion phase of the business cycle. To explain these phenomena, they propose a wage "poaching" mechanism that leads to worker flows from small to large firms. This paper postulates an alternative mechanism by which the interaction between labor search and lumpy capital contributes to the propagation of business cycles and the allocation of workers between small and large firms.

The Khan and Thomas (2003) model this paper builds on was designed to capture the empirical fact that individual firms forgo investing during some periods and have dramatic surges in investment during some other periods.[2] Cooper and Haltiwanger (2006) find that a model with non-convex adjustment costs and irreversibility of capital fits prominent features of observed investment behavior at the micro level. Interestingly, Cooper, Haltiwanger and Wills (2006) find a similar discrete adjustment pattern for employment. They use a labor search model with non-convex vacancy posting costs to explain this fact. Their paper abstracts from capital. In this paper, a non-convex capital adjustment cost generates both lumpy capital and lumpy employment adjustments.

The rest of the paper is organized as follows. Section 2 describes the data and facts; section 3 sets up the model; section 4 defines the equilibrium and discusses the model solution and implications; section 5 sketches the computational algorithm; section 6 calibrates

[2] See Caballero, Engel and Haltiwanger 1995, Doms and Dunne 1998, Caballero and Engel 1999, Cooper and Haltiwanger 2006, and Gourio and Kashyap 2007 for empirical evidence; see Thomas 2002, Khan and Thomas 2008, Bachmann, Caballero and Engel 2006, and Gourio and Kashyap 2007 for theoretical models.

the model parameters; and section 7 analyzes the results. Finally, section 8 concludes.

2 Data and Facts

The data used in this paper come from the Business Employment Dynamics (BED) survey (1992-2007). Firm size is defined by the current number of employees. Small firms are firms with 1-249 employees (49.3% employment share).[3] The data set covers the entire private sector, including all firms covered under state unemployment insurance (UI) programs (which account for 98% employment). The data are measured quarterly.

The data set reports the changes in employment between each quarter's third month. Job creation is the sum of all employment gains at (i) continuous firms expanding their employment, and (ii) "opening" firms reporting either positive employment for the first time or after reporting zero employment in the previous quarter. Job destruction is the sum of all employment losses at (i) continuous firms contracting their employment, and (ii) "closing" firms either disappearing or reporting zero employment after reporting positive employment in the previous quarter. Using this data set, table 2.1 and figure 2.1 exhibit the stylized facts mentioned in the introduction.

Table 2.1 shows the cross correlations between output and job creation and destruction in small and large firms. (1) Job creation in both small and large firms is positively correlated with output, so it is procyclical. (2) Job destruction in small firms is positively correlated with output, while job destruction in large firms is negatively correlated with output. So job destruction in small firms is procyclical, while job destruction in large firms is countercyclical. (3) The standard deviations of job creation and destruction in large firms are about 2.5 times as large as in large firms.

[3] The Small Business Administration (SBA) has defined small businesses in different ways. In the late 1950s, the agency viewed as "small" all industrial establishments with fewer than 250 employees. So the early studies use this definition (e.g. Davis and Haltiwanger 1992). In 1988, reflecting the growing sizes of businesses in the United States, the SBA was defining any firm with 500 or fewer empoyees as small, though the acceptable maximum number of employees might vary by industry group: 500 employees for most manufacturing and mining industries; 100 employees for all wholesale trade industries. A more precise breakdown of the size categories in use by the SBA is: under 20 employees, very small; 20-99, small; 100-499, medium-sized; and over 500, large (SBA, Annual Report, 1988, 19. Also see Blackford 1991).

Table 2.1 Cyclical Behavior of the U.S. Job Creation and Job Destruction:

In Small and Large Firms

Deviations from Trend, 1992:III-2007:I

		Cross-Correlation of Output with								
Variable	*SD%*	$x(-4)$	$x(-3)$	$x(-2)$	$x(-1)$	x	$x(+1)$	$x(+2)$	$x(+3)$	$x(+4)$
GDP	0.84	0.354	0.510	0.707	0.852	1.0	0.852	0.707	0.510	0.354
C_S	2.51	0.329	0.486	0.611	0.683	0.618	0.527	0.332	0.258	0.052
C_L	6.18	0.275	0.402	0.462	0.483	0.450	0.380	0.255	0.211	−0.024
De_S	2.51	−0.150	−0.099	−0.069	0.016	0.182	0.376	0.490	0.535	0.595
De_L	6.81	−0.244	−0.257	−0.298	−0.246	−0.178	0.054	0.194	0.412	0.547

Note: The variables: C_S (C_L): log of job creation in small firms (large firms); De_S (De_L): log of job destruction in small firms (large firms). The data are quarterly series and expressed as deviations from a Hotric-Prescott filter with smoothing parameter 1600.

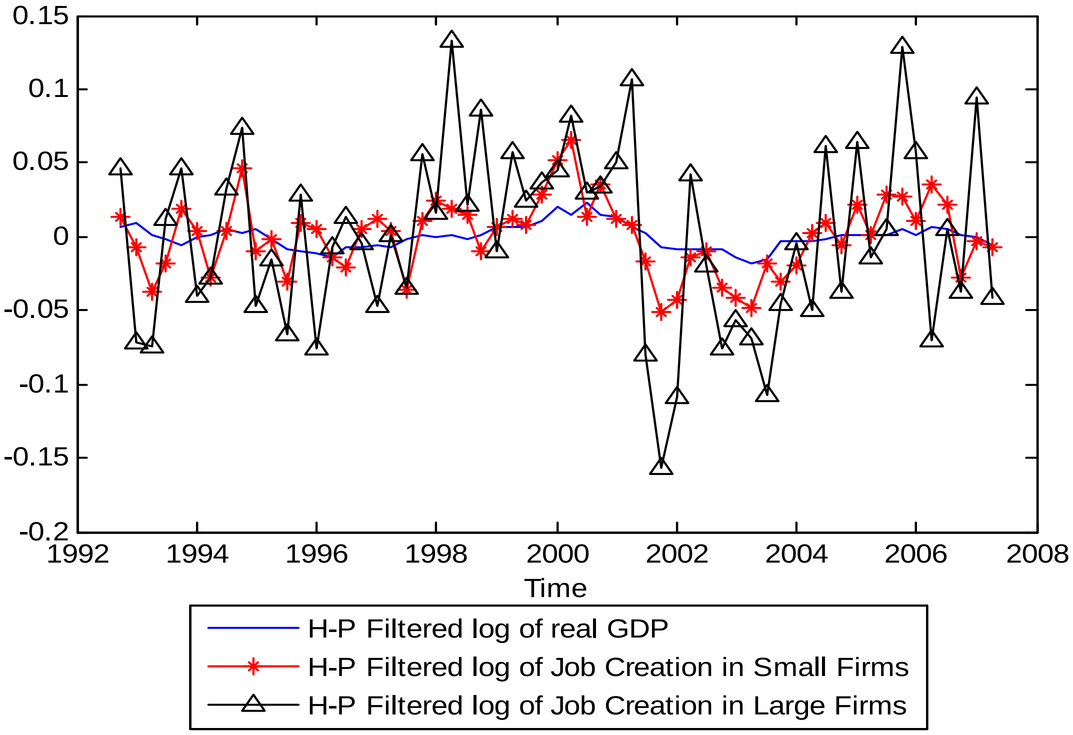


Figure 2.1.a H-P Filtered Cyclical Component of Job Creation in Small and Large Firms

Figures 2.1.a and 2.1.b visualize the deviations of log job creation and log job destruction in small and large firms from their Hotric-Prescott trend, compared to the deviations of log GDP from its Hotric-Prescott trend. Figure 2.1.a shows that job creation rate in small firms move together with job creation rate in large firms and that job creation rate in both small and large firms increases when GDP growth rate is high. So job creation is procyclical in both small and large firms. Moreover, job creation rate goes up and down by more in large firms implying that job creation is more volatile in large firms. Figure 2.1.b shows that, in economic downturns when GDP growth rate is low, job destruction rate first increases in both small and large firms, but job destruction rate in small firms may start to decrease while job destruction rate in large firms still goes up; in economic booms, job destruction rate first decreases in both small and large firms, but job destruction rate in small firms may start to increase while job destruction rate in large firms still goes down. So job destruction in small firms may be procyclical, while job destruction in large firms is countercyclical. Moreover, job destruction rate goes up and down by more in large firms implying that job destruction is more volatile in large firms.

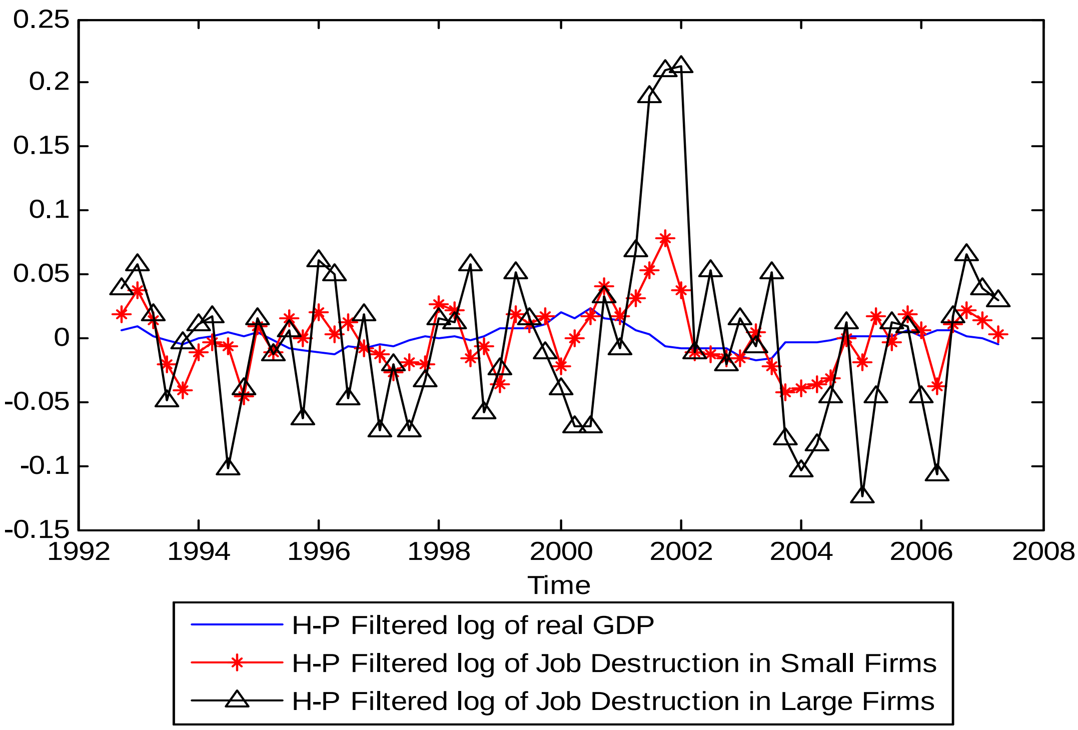


Figure 2.1.b H-P Filtered Cyclical Component of Job Destruction in Small and Large Firms

Figure 2.2 Firm Sizes and Job Creation Rate and Destruction Rate

To complete the analysis of the data, figure 2.2 shows the first moments of job creation and job destruction. The average job creation rate (job creation divided by the total number of employees) and job destruction rate (job destruction divided by the total number of employees) are higher in small firms.

The above facts are described by data at firm level. Using the unpublished data at establishment level from the BED survey, Moscarini and Postel-Vinay (2008) find that the pattern of establishment size dynamics (employment dynamics) over the last two business cycles closely resembles that of firm size dynamics. Part of this resemblance is due to the fact that most (small) firms are mono-establishment, while large establishments tend to be part of large firms, as shown in Table 2.2.

Table 2.2 Firm Sizes and Establishments

Firm size category	Average number of establishments	Mean establishment size
all	1.26	15.58
$1-4$	1.00	2.10
$5-9$	1.01	6.49
$10-19$	1.05	12.75
$20-99$	1.32	29.80
$100-499$	3.82	50.71
500 and up	61.98	53.46

Source: Moscarini and Postel-Vinay (2008), according to County Business Pattern data set

In general, employment dynamics show co-movements in different sectors (Moscarini and Postel-Vinay 2008). The manufacturing sector is different since its establishments are larger on average. Nevertheless, as shown in Davis, Haltiwanger and Schuch (1996) using U.S. manufacturing industry data from 1972 to 1986, during recessions, large establishments experience sharply higher job destruction rates, so their contribution to the job destruction rises. Although they did not explicitly point out that small establishments have procyclical job destruction, it is implied by table 2.3 (quoted below from their book) since job creation and job destruction are positively correlated in small establishments.

Table 2.3 Correlation between Job creation and Destruction by Establishment Sizes

Establishment size category	Correlation of job creation and destruction
$0-19$	0.45
$20-49$	0.11
$50-99$	-0.15
$100-249$	-0.47
$250-499$	-0.47
$500-999$	-0.44
1000 and up	-0.43

Source: Davis, et. al. (1996) according to the Annual Survey of Manufactures between 1972 and 1986.

During expansion years, the percentage of job destruction from establishment shutdown increases by more in large firms than in small firms. This rules out the hypothesis that the main reason for the increased job destruction during expansion years is the increased entry and exit.

Table 2.4 Job destruction from shutdown in establishments with different sizes in U.S. manufacturing industry

	Recession years	Expansion years	Change
fewer than 50	30%	34%	113%
50-249	25%	30%	120%
250-999	16%	22%	138%
1000 or more	8%	14%	175%

Source: Schuh and Triest (1998) according to the Annual Survey of Manufactures between 1972 and 1986

For easy exposition, the production unit in the model below will be an establishment. I will also impose the strong assumption that large firms are composed of large establishments while small firms are composed of solely small establishments. With this assumption, the model's predictions apply to both firm sizes and establishment sizes.

3 The Model

3.1 Preferences

The economy is populated by a unit measure of identical households. Households face the standard consumption-saving problem. In addition, they face different opportunities for exchanging labor services. In particular, individuals either have a job opportunity or not, and job opportunities come and go at random. Having a job opportunity means being matched with an establishment, and having the opportunity to negotiate a labor contract that stipulates the terms by which labor services are exchanged for wages. This household structure improves the tractability of the model in an environment with search frictions (see Shi 1997).

A typical household has preferences represented by a utility function of the following form:

$$E_0 \sum_{t=0}^{\infty} \beta^t [U(c_t) - A\ N_t]$$

where c_t denotes consumption, N_t denotes the fraction of individuals being employed, and $0 < \beta < 1$ is the discount factor. The function U is increasing and concave in c_t. A is the marginal disutility of working. This utility function can be interpreted as a reduced-form of the indivisible labor model in Hansen (1985) and Rogerson (1988).[4]

3.2 Production Technology

Output, which can be consumed or invested, is produced by a large number of establishments with the following production function:

$$y = zk^a n^b, \tag{3.1}$$

[4] In Hansen (1985) the utility function takes the form

$$N(\log c + A \log(1-h)) + (1-N)(\log c + A \log 1),$$

where h is working hours. By rearranging it and omitting the constant terms we can obtain a momentary utility function of the form $\log(c) - A\log(1-h)N$. h is assumed to be constant in this paper.

where z is aggregate productivity, k is capital, n is labor, $a > 0$, $b > 0$, and $a + b < 1$. Aggregate productivity is a stochastic variable common to all establishments, and follows a Markov process with a finite support and a transition matrix Π described by

$$\Pr(\ z' = z_j \mid z = z_i\ ) = \pi_{ij} \geq 0,$$

and $\sum_{j=1}^{J} \pi_{ij} = 1$ for each $i = 1, ...J$.

3.3 Capital Adjustment

An establishment's capital evolves over time according to

$$k' = (1 - \delta)k + i, \tag{3.2}$$

where i is the establishment's current investment and $\delta \in (0, 1)$ is the rate of capital depreciation.

After current production takes place, each establishment has an opportunity to invest with probability ψ.[5] This opportunity enables establishments to make a positive investment with a fixed cost of capital adjustment $\xi \in (0, \bar{\xi})$ drawn from a time-invariant distribution $G(\xi)$ common to all establishments. Within a period, the capital adjustment cost is fixed at the establishment level and is independent of the level of capital adjustment. At any point in time, given the differences in investment opportunities and in the magnitudes of fixed adjustment costs across establishments, some establishments will adjust their capital stocks while others will not. As a result, establishments possess different capital stocks even in the absence of idiosyncratic productivity shocks.

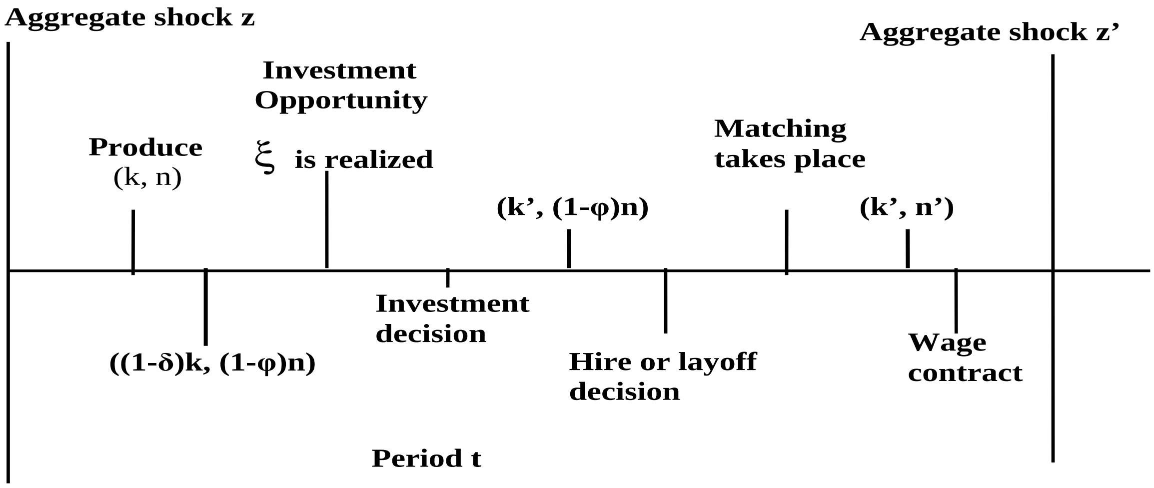
3.4 Labor Search

Workers and producers are brought together through a search process. A worker who is matched with a producer earns a wage specified by a state-contingent contract that depends on the establishment's size and marginal labor productivity. Workers are bound by the contract until they are fired or hit by an exogenous job separation shock. In order to have a clear perspective, I first describe the order of events within a period.

[5] The main reason for allowing this random opportunity of investment is to reconcile the differences in frequencies of investment and employment adjustments. The usual frequency of investment is one year, while the employment adjustment happens every month. So ψ is taken as 1/12 in this paper since a typical period is one month here.

3.4.1 Time Line

The timing of events within a period is described as follows: (1) the aggregate shock is realized; (2) establishments produce with the capital and the workers inherited from the past; (3) investment opportunity shocks are realized and establishments with opportunities to invest draw capital adjustment costs from the distribution $G(\xi)$ and make capital adjustment decisions; (4) establishments decide how many workers they would like for the next period and either fire workers or post vacancies; (5) unemployed workers and vacancies are matched randomly and a state-contingent contract is signed; and (6) the period concludes and the next period starts with the same order of events.



Note that matching is completed before the next period's aggregate productivity shock is realized, and no firing is allowed between the time matching takes place and the next production period.

3.4.2 Matching Mechanism

Firms are allowed to post multiple vacancies and every position is matched randomly. The aggregate matching function is $M(\tilde{\mathbf{v}}, (1-N))$, where $\tilde{\mathbf{v}}$ is the aggregate number of vacancies, and $1-N$ is the aggregate unemployment. Establishments can recruit by posting vacancies, v, with a vacancy cost $e > 0$. The proportion of vacancies that are filled, $x \in [0, 1]$, is random and distributed according to $f(x)$, which is related to the aggregate matching function as follows:

$$f(x) = C_v^{xv} h^{xv} (1-h)^{v-xv}.$$

Here, $h = M(\tilde{\mathbf{v}}, (1-N)) \ / \ \tilde{\mathbf{v}}$ represents the average vacancy-filling rate, $C_v^{xv} \equiv v!/[(xv)! \ (v-xv)!]$ represents the number of ways that xv out of v vacancies can be filled, and v is the number of vacancies posted by an establishment.[6] Every establishment takes $f(x)$ as given. The CDF of x is denoted by $F(x)$.

3.4.3 The Wage Contract

The wage contract is signed before the establishment's state is realized. Once a contract is signed the worker cannot leave the establishment except when being fired or being hit by an exogenous separation shock. The wage is contingent on the marginal productivity of labor of the establishment realized every period according to the following rules: (1) in the case where the marginal productivity of labor is not greater than the disutility of working, the wage is equal to the disutility of working in terms of good, so $w = A/p$, where p is the utility value of current goods; (2) in the case where the marginal productivity of labor is greater than the disutility of working, $w = (MP_L + A/p)/2$, where MP_L is the marginal productivity of labor. The wage is updated every period, and it is identical for new and existing workers.

3.5 Distribution of Establishments and Decision Rules

The aggregate state variables at the beginning of each period are the aggregate productivity shock z and the distribution of establishments $\bar{\boldsymbol{\mu}}$ described by a probability measure $\mu(k,n)$ over capital and employment, which is defined on the product space $S = R_+ \times R_+$. The distribution of establishments evolves over time according to a mapping Γ from the current aggregate state to a new one: $\bar{\boldsymbol{\mu}}' = \Gamma(z, \bar{\boldsymbol{\mu}})$. This mapping is endogenous and determined below.

Let $V^0(k, n; z_i, \bar{\boldsymbol{\mu}})$ denote the expected value of an establishment at the beginning of a period, prior to the realization of its adjustment cost but after the determination of $(k, n; z_i, \bar{\boldsymbol{\mu}})$. Let $\tilde{V}^1(k, n; z_i, \bar{\boldsymbol{\mu}})$ denote the expected discounted value of an establishment that enters the period with (k, n), and has no opportunity to invest. Let $V^1(k, n, \xi; z_i, \bar{\boldsymbol{\mu}})$ denote

[6] Note that xv is not an integer in this paper. The computation involves approximation.

the expected discounted value of an establishment that enters the period with (k,n), has an opportunity to invest, and draws an adjustment cost ξ.

Consider an establishment that has drawn the investment cost ξ and has decided to invest. The expected future value of the establishment, net of investing and hiring costs, is

$$\tilde{\Delta}_I = \max_{k'_I}\left\{-\xi - i + \max_{v,f^i}\left[-ev + \sum_{j=1}^{J}\pi_{ij}d_j(z,\bar{\boldsymbol{\mu}})\int_0^1 V^0(k'_I,n';z_j,\bar{\boldsymbol{\mu}}')F(dx)\right]\right\}. \tag{3.3}$$

Here, e is the vacancy posting cost. If the establishment invests, it chooses an optimal level of k'_I. The investment is given by $i = k'_I - (1-\delta)k$. n is the number of workers in the current period. The establishment chooses to either post vacancies v or to fire workers f^i. The number of workers in the next period also depends on the realization of the individual matching rate x. The evolution of employment for an establishment is

$$n' = (1-\varphi)n + vx - f^i\ , \tag{3.4}$$

where **either** v **or** f^i is positive, or both are equal to zero. $d_j(z_i,\bar{\boldsymbol{\mu}})$ is the discount factor applied by establishments to their next period expected value if aggregate productivity at that time is z_j and current productivity is z_i. (Except where necessary for clarity, I suppress the indices for current aggregate productivity below.) Suppose, instead, that this establishment chooses not to invest. Then, the net expected future value would be

$$\tilde{\Delta}_{no} = \max_{v,f^i}\left[-ev + \sum_{j=1}^{J}\pi_{ij}d_j(z,\bar{\boldsymbol{\mu}})\int_0^1 V^0(\ (1-\delta)k,n';z_j,\bar{\boldsymbol{\mu}}')F(dx)\right]. \tag{3.5}$$

The value functions $V^0(k,n;z_i,\bar{\boldsymbol{\mu}})$, $\tilde{V}^1(k,n;z_i,\bar{\boldsymbol{\mu}})$, and $V^1(k,n,\xi;z_i,\bar{\boldsymbol{\mu}})$ satisfy the following Bellman equations:

$$V^0(k,n;z_i,\bar{\boldsymbol{\mu}}) \equiv (1-\psi)\tilde{V}^1(k,n;z_i,\bar{\boldsymbol{\mu}}) + \psi\int_0^{\bar{\xi}} V^1(k,n,\xi;z_i,\bar{\boldsymbol{\mu}})G(d\xi), \tag{3.6}$$

$$\tilde{V}^1(k,n;z_i,\bar{\boldsymbol{\mu}}) = \ zF(k,n) - wn + \tilde{\Delta}_{no}, \tag{3.7}$$

and

$$V^1(k,n,\xi;z_i,\bar{\boldsymbol{\mu}}) = \ zF(k,n) - wn + \max(\tilde{\Delta}_I,\tilde{\Delta}_{no}). \tag{3.8}$$

Establishments start producing right after the aggregate shock is realized. After production, an establishment with an opportunity to invest chooses the optimal investment level. Those with positive investments pay the capital adjustment costs. However, if establishments do not invest, this cost is avoided as shown in $\tilde{\Delta}_{no}$. Next, establishments make hiring or firing decisions. They either post vacancies with cost e or fire workers without incurring any costs, depending on the expected future aggregate conditions.

Let $k^f(k, n, \xi; z, \bar{\boldsymbol{\mu}})$ denote the choice of capital in the next period by establishments of type (k, n) with adjustment cost ξ. Let $v(k, n; z, \bar{\boldsymbol{\mu}})$ denote the choice of vacancies and $f^i(k, n; z, \bar{\boldsymbol{\mu}})$ denote the number of layoffs by all type (k, n) establishments. The aggregate employment for the next period is

$$N' = \int_S \int_0^1 \Big[(1-\varphi)n(k, n; z, \bar{\boldsymbol{\mu}}) + v(k, n; z, \bar{\boldsymbol{\mu}})\ x - f^i(k, n; z, \bar{\boldsymbol{\mu}})\Big]\, dF(x)\mu(d\ [k \times n]\ ). \tag{3.9}$$

Let the aggregate number of vacancies be $\tilde{\mathbf{v}} = \int_S\ v(k, n; z, \bar{\boldsymbol{\mu}})\ \mu(d\ [k \times n]\ )$ and the aggregate number of layoffs be $\tilde{f}^i = \int_S\ f^i(k, n; z, \bar{\boldsymbol{\mu}})\ \mu(d\ [k \times n]\ )$.

3.6 The Household's Problem

Each household holds shares of the establishments, which are denoted by a measure λ. The employment N is taken as a state variable. The household chooses current consumption, c, and the number of new shares $\lambda'(k', n')$ to purchase at price $\rho(k', n'; z, \bar{\boldsymbol{\mu}}')$. Denote $\bar{\lambda}$ as the distribution of shares and $\bar{\rho}$ as a vestor of the prices. The household's utility maximization problem is described by the Bellman equation below:

$$W(\lambda, N; z, \bar{\boldsymbol{\mu}}) = \max_{\{c, \lambda'\}} \{U(c) - AN + \beta \sum_{j=1}^{J} \pi_{ij} W(\lambda', N'; z_j, \bar{\boldsymbol{\mu}}')\}. \tag{3.10}$$

The budget constraint is:

$$\begin{aligned} & c + \int_S \rho(k, n; z, \bar{\boldsymbol{\mu}})\lambda'(d[k \times n]) \\ \leq & \int_S w(k, n; z, \bar{\boldsymbol{\mu}})n(k, n;\ z, \bar{\boldsymbol{\mu}})\mu(d[k \times n]) + \int_S V^0(k, n; z, \bar{\boldsymbol{\mu}})\lambda(d[k \times n]). \end{aligned} \tag{3.11}$$

Letting $C(\lambda, N; z, \bar{\boldsymbol{\mu}})$ be the policy function describing the optimal choice of current consumption, and $\Lambda(k, n, \lambda, N; z, \bar{\boldsymbol{\mu}})$ be the policy function describing the optimal choice of the shares that the household purchases of the establishments with state $(k,\ n)$.

4 The Equilibrium

4.1 Definition of the Recursive Equilibrium

A recursive equilibrium is consists of a set of value functions $(W, V^0, V^1, \tilde{V}^1)$; a set of policy functions for the household C and Λ; a set of policy functions for the establishments $k^f, v,\ f^i$; a set of prices p and $\bar{\rho}$; a set of average matching rate h, and a set of distribution mesures $\bar{\lambda}$ and $\bar{\boldsymbol{\mu}}$ such that:

1. Given the prices $p(z, \bar{\boldsymbol{\mu}})$ and the aggregate matching rate h, V^0, V^1 and $\tilde{V}^1$ satisfies (3.3) - (3.8) and $(k^f, v,\ f^i)$ are the associated policy functions for the establishments;

2. Given the prices $p(z, \bar{\boldsymbol{\mu}})$ and $\bar{\rho}$, W satisfies (3.10) and (C, Λ) are the associated policy functions for the households;

3. The law of motions of aggregate employment and capital stock are consistent with the individual establishments' behavior:

$$N' = \int_S \int_0^1 \left[(1-\varphi) n(k, n; z, \bar{\boldsymbol{\mu}}) + v(k, n; z, \bar{\boldsymbol{\mu}})\ x - f^i(k, n; z, \bar{\boldsymbol{\mu}}) \right] dF(x) \mu(d[k \times n]); \tag{4.1}$$

$$K' = \int_S [(1-\delta) k(k, n; z, \bar{\boldsymbol{\mu}}) + i(k, n; z, \bar{\boldsymbol{\mu}})\ ]\ \mu(d[k \times n]); \tag{4.2}$$

4. The law of motion of $\bar{\boldsymbol{\mu}}$:

$$\bar{\boldsymbol{\mu}}' = \Gamma(z, \bar{\boldsymbol{\mu}});$$

5. The share market clears, i.e. $\Lambda(k, n, \lambda, N; z, \bar{\boldsymbol{\mu}}) = \mu(k, n)$;

6. The goods market clears:

$$\begin{aligned} C(\lambda, N; z, \bar{\boldsymbol{\mu}}) &= \int_S \{ zF(k, n'(k, n; z, \bar{\boldsymbol{\mu}})) \mu(d[k \times n]) \\ &\quad - \psi \int_S \int_0^{\bar{\xi}} (k^f(k, n, \xi; z, \bar{\boldsymbol{\mu}}) - (1-\delta)k) G(d\xi)] \mu(d[k \times n]) \\ &\quad - \psi \int_S D\ [\alpha(k, n)] \mu(d[k \times n]) - \tilde{\mathbf{v}}\ e, \end{aligned} \tag{4.3}$$

where

$$D\ [\alpha(k, n)] = \int_0^{G^{-1}(\ \alpha(k,\ n)\ )} \xi G(d\xi). \tag{4.4}$$

$D\ [\alpha(k, n)]$ is the average value of adjustment costs of all type (k, n) establishments that invest in capital. Letting $\hat{\xi}$ be the highest adjustment cost such that the type (k, n) establishments undertake positive investment and $\alpha(k,n)$ be the fraction of type (k,n) establishments that invest in capital, then $G(\hat{\xi}) = \alpha(k,n)$. An establishment chooses to invest if it draws $\xi \in (0,\hat{\xi})$, and not to invest if it draws $\xi > \hat{\xi}$.

4.2 Model Solution and Discussion

The equilibrium is computed by solving a single Bellman equation that combines establishments' profit maximization problem with the utility maximizing conditions from the household's problem. Let $p(z,\bar{\boldsymbol{\mu}})$ be the utility value of current goods (the multiplier for the budget constraint in the household maximization problem). The first order condition in the household problem gives

$$p(z,\bar{\boldsymbol{\mu}}) = U'(c). \tag{4.5}$$

The discounting factor is defined as $d_j(z,\bar{\boldsymbol{\mu}}) \equiv \frac{\beta U'(\ c')}{U'(\ c)} = \frac{\beta p(z_j,\ \bar{\boldsymbol{\mu}}')}{p(z,\ \bar{\boldsymbol{\mu}})}$.

Establishments use $p(z,\bar{\boldsymbol{\mu}})$ to evaluate current output. A reformulation of equations (3.3) - (3.8) yields an equivalent description of the establishments' dynamic problem.[7] Suppressing the arguments of the price functions, the value function of an establishment with no investment opportunity becomes

$$\tilde{V}^1(k,n;z_i,\bar{\boldsymbol{\mu}}) = [\ zF(k,n) - wn + (1-\delta)k]\ p\ +\ \Delta_{no}\ , \tag{4.6}$$

and the value function of an establishment with investment opportunity and with a draw ξ becomes

$$V^1(k,n,\xi;\ z_i,\bar{\boldsymbol{\mu}}) = [\ zF(k,n) - wn + (1-\delta)k]\ p +\ \max(\Delta_I,\Delta_{no}). \tag{4.7}$$

In equation (4.7), Δ_I is the net value of achieving the target capital, while Δ_{no} is the continuation value of the establishment if it does not invest in capital. Δ_I and Δ_{no} are given below:

$$\Delta_I = \max_{k'_I}\left\{-\xi p - k'_I p + \max_{v,f^i}\left[-evp + \beta\sum_{j=1}^{J}\pi_{ij}\int_0^1 V^0(k'_I,n';z_j,\bar{\boldsymbol{\mu}}')F(dx)\right]\right\}, \tag{4.8}$$

[7] Following Khan and Thomas (2003), rather than subtracting investment from current profits, I let the value of non-depreciated capital be included in the current profits, and let the establishment "repurchase" its capital stock each period. This is done only for expositional convenience.

and

$$\Delta_{no} = -(1-\delta)kp + \max_{v,f^i}\left[-evp + \beta\sum_{j=1}^{J}\pi_{ij}\int_0^1 V^0((1-\delta)k, n'; z_j, \bar{\boldsymbol{\mu}}')F(dx)\right]. \tag{4.9}$$

Here, k_I' is the next period's capital level if the establishment chooses to invest. The employment evolves according to (3.4), and $V^0(k, n; z_i, \bar{\boldsymbol{\mu}})$ is defined in (3.6).

Now I examine the establishments' decisions. After the current period production takes place, an establishment with investment opportunity draws ξ. If this ξ is relatively low, the establishment undertakes investments, and the optimal capital stock $\hat{k}_I'(n; z_j, \bar{\boldsymbol{\mu}})$ solves the right side of (4.8). Denote $X = \beta\int_0^1 \sum_{j=1}^{J}\pi_{ij}V^0(k_I', n'; z_j, \bar{\boldsymbol{\mu}}')F(dx)$ as the expected future value for easy exposition.

Note that the optimal level of capital stock next period $\hat{k}_I'$ is independent of the current level of capital stock k and capital adjustment cost ξ. This is because both the marginal cost of purchasing new capital, p, and the marginal benefit of purchasing new capital, the marginal increase in the expected future value of the establishments with respect to k_I', $\left.\frac{\partial X}{\partial k_I'}\right|_{\hat{k}_I'} = \left[\beta\int_0^1\sum_{j=1}^{J}\pi_{ij}\frac{\partial\, V^0\ (k_I',\ n';\ z_j,\ \bar{\boldsymbol{\mu}}')}{\partial\ k_I'}F(dx)\right]_{\hat{k}_I'}$, do not depend on k and ξ. As a result, all establishments with positive investments and equal employment stocks n will choose a common level of capital for the next period. Because the optimal level of capital in the next period is independent of the current capital level, the net value of achieving the optimal capital level, $\Delta_I(\xi, n; z, \bar{\boldsymbol{\mu}})$, is also independent of current capital. However, both the optimal level of capital stock, $\hat{k}_I'$, and the level of Δ_I depend on the current level of employment in the establishments through (3.4). This is an important implication and is restated in the following proposition. (The proof is straight forward and therefore I am omitting it.)

Proposition 1 *With labor search frictions, establishments' optimal levels of capital stock conditional on making positive investment are independent of the current individual capital stocks, but they depend on the establishments' sizes measured by their current employment.*

Labor market search is important for the non-trivial dependence of the optimal capital stock on an establishment's current employment. If there were no search frictions in the labor market, the model would predict that all the establishments would choose the same optimal capital stock, and one level of capital stock would be associated with one level of employment, as in Khan and Thomas (2003). This unrealistic prediction is avoided in the current setting by the presence of search frictions in the labor market. With random matching, the establishments that have drawn the same capital adjustment cost and desire to have the same capital stock will still end up with different levels of employment in the next period. Thus, for a given level of current employment stock, there is a distribution of possible states of employment in the next period. This distribution depends on the number of vacancies posted. Unless the value function $V^0(k'_I, n'; z_j, \bar{\boldsymbol{\mu}}')$ is linear in n, the expected future values of establishments with identical k'_I but different distributions of possible levels of n' will not be equal.

Now consider the establishments that do not undertake investments. Since these establishments do not invest, their capital stock depreciates. The continuation value for such establishments is Δ_{no}, which is positively related to the current capital stock. Again, all the establishments with type (k, n) will choose the same level of v or f^i, but the realized levels of the next period's employment will depend on the realization of the individual job filling rate.

From (4.8) and (4.9) it is now clear that an establishment will undertake positive investment only if the net value of achieving the target capital, $\Delta_I(\xi, n; z, \bar{\boldsymbol{\mu}})$, exceeds its continuation value under non-adjustment $\Delta_{no}(k, n; z, \bar{\boldsymbol{\mu}})$. It follows immediately that an establishment of type (k, n) will undertake capital adjustments if its fixed adjustment cost, ξ, falls below a threshold value, $\tilde{\xi}(k, n; z, \bar{\boldsymbol{\mu}})$, which depends on (k, n). At $\xi = \tilde{\xi}(k, n; z, \bar{\boldsymbol{\mu}})$, an establishment is indifferent between adjusting capital stock and allowing its capital stock to depreciate. That is,

$$\Delta_i(\tilde{\xi}, n; z, \bar{\boldsymbol{\mu}}) = \Delta_{no}(k, n; z, \bar{\boldsymbol{\mu}}).$$

Define the threshold value of capital adjustment cost

$$\hat{\xi}(k, n; z, \bar{\boldsymbol{\mu}}) \equiv \min\left\{\bar{\xi}, \max\{0, \tilde{\xi}(k, n; z, \bar{\boldsymbol{\mu}})\}\right\}.$$

Establishments with adjustment costs at or below $\hat{\xi}(k, n; z, \bar{\boldsymbol{\mu}})$ will adjust their capital stock. This threshold value determines the investment hazard rate.

Another implication of introducing labor search is that the investment hazard rate now is not only determined by the capital stock, but also by the employment stock. In Khan and Thomas (2003) the investment hazard rate strictly decreases with the capital stock, which implies that small firms always have higher investment hazard rates. This is not true in this paper. Large establishments may have a higher investment hazard rate in a variety of cases. Most obviously, for example, among establishments with an identical capital stock the investment hazard rate increases with size (current employment). This is because capital and labor are complementary in production. First, the higher employment level means a higher marginal capital productivity. Since the labor market is frictional, the establishment cannot change its employment immediately. This higher marginal capital productivity leads to higher investment hazard rate. Second, large establishments need less new workers to work with the newly invested capital. A small number of vacancies v is posted, and that means smaller vacancy posting costs vep and less cost resulting from the uncertainty of recruiting.

Substitute n' from (3.4) into the expected future value X gives

$$X = \beta \int_0^1 \sum_{j=1}^{J} \pi_{ij} V^0(k_I', (1-\varphi)n + vx; z_j, \boldsymbol{\bar{\mu}}')F(dx), \tag{4.10}$$

if $v \geq 0$. It is obvious that the future value X depends on the current employment n, and the individual vacancy-filling rate x. The distribution $F(x)$ is determined by the average vacancy-filling rate. The first effect comes from that $\frac{\partial^2 X}{\partial k_I' \partial n}\Big|_{\hat{k}_I'} > 0$, i.e. capital and labor are complementary. For the second effect, the larger the n, the less the vacancies v needed to post, and the smaller the impact of the labor market tightness on X. For large establishments the risk of investment resulting from uncertainty of recruiting is diversified by the large n. Note that the curvature of the production function and, therefore, of the value function V^0 can be important for the quantitative impact of labor search friction and labor market tightness.

5 Computational Algorithm

In the presence of aggregate uncertainties, establishments need to form rational expectations about the future values induced by their current behavior. To identify the expectation rules that are consistent with rational expectations, I use a guess-and-verify method.

The main computational difficulty of dynamic heterogeneous establishment models is that in order to predict prices, consumers need to keep track of the evolution of the establishment distribution. In other words, the distribution of establishments is one of the aggregate state variables, which means the state space has infinite dimensions. To deal with the problem of a large dimensional state space, I use a small number of moments to approximate the distribution functions as in Krusell and Smith (1998) and, in a context similar to the current paper, Khan and Thomas (2003).

Another problem is that most of the constraints in the maximization problems are nonlinear. Following Khan and Thomas (2003) I solve nonlinearly for V^0 across a multidimensional grid of points, using cubic splines to interpolate function values at other points. Johnson et. al. (1993) has shown that this type of multivariate spline approximation is more efficient than multilinear grid approximation.

In a main loop, I guess and verify the functional forms that predict the current equilibrium price, p, the current aggregate vacancy, $\tilde{\mathbf{v}}$, and next period's proxy endogenous state, m'. I denote these functional forms by $p = \hat{p}(z, m; \chi_l^p)$, $\tilde{\mathbf{v}} = \hat{v}(z, m; \chi_l^v)$ and $m' = \hat{\Gamma}(z, m; \chi_l^m)$, where m is a vector of the moments of the distribution of capital stock and employment across establishments, χ_l^p, χ_l^v and χ_l^m are parameters that are determined repeatedly using a procedure explained below, and l indexes these iterations. Every iteration in the main loop contains the following two steps: the inner loop and the outer loop. Every iteration is started with an initial guess of $(\chi_l^p, \chi_l^v, \chi_l^m)$.

1) The inner loop: the first step involves repeated application of the contraction mapping implied by (4.6)-(4.9), (3.4), and (3.6), given the price (4.5) and the matching function (3.10), to solve for V^0. I use $(\chi_l^p, \chi_l^v, \chi_l^m)$, having replaced $\bar{\boldsymbol{\mu}}$ with m and Γ with $\hat{\Gamma}$ in (4.6)-(4.9), (3,4) and (3.6), to predict the next period's moments of the distribution of capital as well as employment and the current period's equilibrium price and aggregate vacancy. Using the aggregate levels of employment and vacancies, I can calculate the aggregate matching rate. Given these aggregates, I can solve for V^0 at each point on a grid of values for $(k; n; z; m)$ by iterating over establishments' problems.

2) The outer loop: the second step simulates the economy for T periods. The simulated data are used to estimate the expectation parameters $(\chi_l^p, \chi_l^v, \chi_l^m)$. At the beginning of any

period, $t = 1, 2, ...T$, the actual distribution of establishments over capital k and employment n, $\bar{\boldsymbol{\mu}}_t$, is given. I calculate the first moments m directly from the actual distribution $\bar{\boldsymbol{\mu}}_t$. Then I use the approximated mapping $\hat{\Gamma}$ to specify expectations of m'. This procedure determines the expected future value $\beta \int_0^1 \sum_{j=1}^{J} \pi_{ij} V^0(k', n'; z_j, \bar{\boldsymbol{\mu}}')F(dx)$ for any establishment with (k', n'), given V^0 obtained from the first step. After specifying the expectation rules for establishments, I proceed to find the equilibrium price and matching rate: (i) I guess a price and matching rate pair, $(\tilde{p}\ ,\ \tilde{M})$; (ii) given those price and matching rate, I solve establishments problems to find k^f, v, and f^i using (3.4), (3.6) and (4.6)-(4.9), and I aggregate these variables; (iii) the aggregate level of employment is given by (4.2); (iv) the implied price is obtained from (4.5), and the implied matching rate can be computed given the aggregate level of vacancies $\tilde{\mathbf{v}}$ and the aggregate unemployment $\tilde{\mathbf{u}}$; (v) I check whether the implied price and matching rate converge to the initial guess $(\tilde{p},\ \tilde{M})$: if the price and matching rate converge, I calculate the distribution of establishments in the next period, $\bar{\boldsymbol{\mu}}_{t+1}$; if the price and matching rate do not converge, I update the guess for $\tilde{p}$ and $\tilde{M}$ and return to step (i). After the completion of the $T-$periods simulation, the resulting data $(p_t,$ $\tilde{\mathbf{v}}_t,\ m_t)_{t=1}^T$ are used to re-estimate $(\chi_l^p,\ \chi_l^v,\ \chi_l^m)$ using OLS. The estimated $(\chi_l^p,\ \chi_l^v,\ \chi_l^m)$ is used in the next iteration.

To sum up, first, I find the value functions of establishments V^0 given a guess of the expectation parameters $(\chi_l^p,\ \chi_l^v,\ \chi_l^m)$; second, given V^0, I simulate the model for T periods and obtain simulated data $(p_t, \tilde{\mathbf{v}}_t, m_t)_{t=1}^T$ to estimate the parameters $(\chi_l^p,\ \chi_l^v,\ \chi_l^m)$. I iterate these two steps until the parameters $(\chi_l^p,\ \chi_l^v,\ \chi_l^m)$ converge. These converged parameters govern the equilibrium expectation rules. Given these parameters, I can simulate the model to obtain data that could be used for analyses.

6 Parameterization

In order to compute the model, I specify the functional forms for U, M, and G. Following the literature, I use an isoelastic utility function for consumption, $U(C) = \frac{C^{\ 1-\theta}}{1\ -\ \theta}$, and a standard matching function, $M\ (\tilde{\mathbf{v}},\ \tilde{\mathbf{u}}) = \min\ \{\tilde{\mathbf{v}},\ \tilde{\mathbf{u}},\ \kappa\tilde{\mathbf{v}}^{\gamma}\tilde{\mathbf{u}}^{1-\gamma}\}$, where $\kappa > 0$, and $\gamma \leq 1$. Without loss of generality, I let the capital adjustment cost have a Beta distribution with shape parameters β_p and β_q. The uniform distribution is a special case of the Beta distribution with $\beta_p = 1$ and

$\beta_q = 1$. Since the domain of a Beta distribution is $[0,1]$, I normalize the capital adjustment cost shock $\xi \in [0,\ \bar{\xi}]$ by $\bar{\xi}$, so that $\xi/\bar{\xi}$ is distributed according to the Beta distribution. Denote the probability distribution function (PDF) as $g(\xi)$, so $g(\xi) = \frac{1}{B(\beta_p,\beta_q)}\xi^{\beta_p-1}(1-\xi)^{\beta_q-1}$, where $B\ ()$ is the Beta function, $B(\beta_p,\beta_q) = \int_0^1 \xi^{\beta_p-1}(1-\xi)^{\beta_q-1}d\xi$.

The rest of this section describes the observations in the U.S. economy, which are used to calibrate the parameters of the model. The parameters to be calibrated are the discount factor β, the coefficient of risk aversion θ, the marginal disutility of working A, the capital and labor shares in the production function a and b, the capital depreciation rate δ, the capital adjustment cost upper bound $\bar{\xi}$, the distributional parameters β_p and β_q, the labor matching function technology parameters κ and γ, the vacancy posting cost e, the exogenous job separation rate φ, and the parameters governing the aggregate productivity shocks. I choose the model time period to be one month to accommodate for the relatively short average durations of unemployment and vacancies in the U.S. economy. Since the average durations of investment is one year, the investment opportunity ψ is set to $1/12$. Calibrating to an annual interest rate of 4 percent, which is a standard value in the macro literature, requires a monthly discount factor β equal to 0.996.

Since the production unit is interpreted as an establishment, I follow Veracierto (2008) in determining the components of the empirical counterparts of variables. The capital components in this paper do not include land, residential structures, and consumer durable goods. The empirical counterpart for investment is associated in the National Income and Product Accounts (NIPA) with nonresidential investment and changes in business inventories. Output is calculated as the sum of these investment and consumption measures. The quarterly capital-output ratio and the investment-output ratio corresponding to these measures are 6.8 and 0.15, respectively (Veracierto 2008). At stationary equilibrium $I/Y = \delta(K/Y)$, these ratios require the quarterly capital depreciation rate to equal 0.0221. The implied monthly capital depreciation rate is approximately 0.008.

Given the values for β and δ, and given that the capital share in the production function satisfies

$$a = \frac{(1/\beta - 1 + \delta)K}{Y},$$

matching the U.S. capital-output ratio requires choosing a value of a equal to 0.22. Similarly,

$b = 0.64$ is selected to generate the share of labor in NIPA.

The aggregate productivity shock is constrained to follow a standard AR(1) process:

$$z_j = \rho z_i + \varepsilon_j$$

where ε_j is an i.i.d. random variable obeying a normal distribution with mean zero and standard deviation σ. Prescott (1986) selected a value of 0.95 for auto-correlation and a value of 0.00763 for the standard deviation, so the measured Solow residual in the model economy replicates the behavior of the measured Solow residual in the quarterly data. Veracierto (2008) uses the private sector output and capital data and finds a smaller value for the standard deviation, 0.0063. In this paper, I follow the estimates from Veracierto and modify them to suit the period length of one month: ρ is approximately 0.98, and the standard deviation σ is approximately 0.0021.[8]

The parameters that govern the distribution of the capital adjustment costs are β_p, β_q, and the upper bond of capital adjustment costs $\bar{\xi}$. The values of these parameters are chosen to match two pieces of evidence on investment spikes and capital adjustment costs reported by Cooper and Haltiwanger (2006): (1) the proportion of establishments with annual investment rates higher then 20% is about 18.6%; and (2) the average adjustment cost paid relative to the capital stock is 0.0091. To match their observations, I set $\bar{\xi} = 0.028K$, $\beta_p = 1.2$, and $\beta_q = 0.8$.

The marginal disutility of working A is an important determinant of aggregate employment N. Thus, $A = 1.44$ is picked to generate an average employment-population ratio of 60%, as observed in the data. Since the population is normalized to 1, the average employment level is 0.6. Here, the labor force is assumed to be constant. Since the average unemployment rate in the U.S. data is about 6%, the labor force is 0.64.[9] This means that unemployment is $\tilde{\mathbf{u}} = 0.64 - N$.

The parameter γ is the elasticity of the matching rate with respect to the aggregate recruiting intensity. I use $\gamma = 0.7$, a value close to Shimer's (2005) estimates. Given the

[8] $\sigma = 0.0063/\sqrt{3(\rho^4 + \rho^2 + 1)}$

[9] The labor force participation rate for people older than 16 years is about 0.75 in U.S. data. This paper uses 0.64, which is considered as the labor force participation rate for all the people.

value of γ, the technology parameter on the matching function, κ, is then determined by

$$\kappa = h \ / \ (\frac{\tilde{\mathbf{u}}}{\tilde{\mathbf{v}}})^{1-\gamma} \quad ,$$

where $h = M\ (\tilde{\mathbf{v}},\ \tilde{\mathbf{u}})/\tilde{\mathbf{v}}$ is the average job filling rate. The monthly average job filling rate is calculated to be 0.49, consistent with an average vacancy duration of about 45 days.[10]

Since in a stationary equilibrium job creation equals job destruction, $(0.64-\tilde{\mathbf{u}}) * 3.7\% = \tilde{\mathbf{v}} * 0.49$. The monthly average job separation rate is 3.7%, according to data for 2000-2008 from the Job Openings and Labor Turnover Survey (JOLTS, published by the Bureau of Labor Statistics). According to this calculation, the average v-u ratio $\frac{\bar{v}}{\bar{u}}$ is approximately 1.125. [11] Using these values for the v-u ratio and an average job filling rate 0.49, I get a value of 0.508 for κ. The empirical counterpart of vacancy posting cost is difficult to identify. I use a value of 0.15 for e, which implies an average vacancy posting cost of approximately 10% of a month's wage bill.

Finally, the parameter θ, which controls the elasticity of goods consumption, indirectly controls the elasticity of aggregate labor supply. Since, according to the literature, the volatility of aggregate employment is as large as that of aggregate output and the two are positively correlated, this paper uses $\theta = 0.4$ so that a 1% increase in GDP is associated with a 1% increase in aggregate employment given a positive productivity shock.

[10] $1-(44/45)^{30} = 0.49$. It should be noted that the average duration for vacancies is commonly reported to be under one month, which should imply the job filling rate close to 1. However, as pointed out by van Ours and Ridder (1992), a distinction should be made between the time a help-wanted advertisement is removed and the time it actually takes to fill a vacant position. These authors report that while 75 percent of all vacancies are filled by applicants who arrive in the first two weeks, it takes on average 45 days to select a suitable employee from the pool of applicants. The same target is used in Andolfatto (1996).

[11] The v-u ratio, $\frac{\bar{v}}{\bar{u}}$, is approximately 0.56 in the U.S. data between 2000 and 2008, the level of unemployment, $\bar{u}$, is from the CPS, and the level of vacancy, $\bar{v}$, is from the JOLTS. The monthly average job opening rate is 2.7%. However, according to Davis, Faberman and Haltiwanger (2007), many establishments hire workers during a month in which they report no job openings. They found that at least 36 percent of hires occur without a prior vacancy, as recorded in JOLTS. Since my paper assumes that all establishments post vacancies in order to hire, to have a steady unemployment rate the v-u ratio needs to be higher than that reported in the literature (for instance, Cooper et. al. 2006 use an average v-u ratio of 0.46).

Table 6.1 Key Parameters

Key parameter	Value	Comment
Disutility from working A	1.44	60% employment-population ratio
Capital adjustment cost upper bound $\bar{\xi}$	$0.028K$	18.6% investment spikes
Matching technology κ	0.508	Vacancy duration of 45 days
Matching rate elasticity γ	0.7	Shimer (2005)
Vacancy posting cost e	0.15	10% of one month wage bills
Exogenous job destruction rate φ	3.7%	3.7% job separation rate

7 Results

7.1 Responses to Permanent Productivity Shocks

The first test for the model is to see if it can replicate the fact that job creation is procyclical in both small and large firms, while job destruction is countercyclical in large firms but, surprisingly, procyclical in small firms. This section shows the responses of job creation and job destruction after a 1% permanent positive productivity shock. I first test the benchmark model with both random capital adjustment costs and random labor market search frictions. Then, I do two experiments to see the separate effects of labor market frictions and capital adjustment costs. In one experiment, I shout down the capital margin in the benchmark model and leave only the frictional labor markets with idiosyncratic productivity differences across establishments. In the other experiment, I shout down the labor market search frictions in the benchmark model. The resulting model is a lumpy capital model with Walrasian labor market. The benchmark model successfully predicts the signs of job creation and job destruction in both small and large establishments. Neither the labor search model with heterogeneous establishments nor the lumpy capital model can generate signs that are consistent with the facts.

7.1.1 Benchmark Model

In the benchmark model, the investment hazard rates increase in response to a positive productivity shock. This is because the future value of investment increases, which in turn raises the endogenous threshold value for the capital adjustment cost below which establishments undertake investments. As the investment rates increase, establishments hire more workers to complement their increased capital stock. As a result, the amount of job creation is higher in both large and small establishments. See table 7.1.

Table 7.1 Change of Job Creation and Destruction - Benchmark Model

Job creation		Job destruction	
Small	Large	Small	Large
+1.93%	+0.63%	+3.65%	−1.13%

The investment hazard rate increases are particularly big in large establishments. The investment hazard rate increases by 10% in small establishments and by more than 30% in large establishments, when I compare establishments with the same capital and labor before and after the shock. To calculate the average change of the investment hazard rate I need to account for the change in the distribution of establishments. On average, investment rate increases by 5% in small establishments and by 14% in large establishments.

The different investment responses by small and large establishments can be explained by the following two effects that labor search frictions have on establishments' investment decisions. First, the distributional effect. Labor market search frictions imply that even if two establishments have the same history of investment, their employment levels can still differ depending on their histories of labor market search outcome. In fact, a smaller size is the result of the firm's lack of success in hiring the desired amount of workers. Since capital and labor are complementary, a higher level of aggregate productivity increases the marginal productivity of capital, conditioning on undertaking lumpy investment, by more in a large establishment than in a small establishment. As a result, investment rate increases are stronger in large establishments than in small establishments.

Second, the effect of labor market tightness. After the permanent positive productivity shock, investment increases and establishments post more vacancies. The labor market becomes tighter (the vacancy-filling rate is low). This tight labor market makes investment in small establishments risky, since they may very well fail to hire workers quickly to complement the increased capital stock. As the tight labor market constraints the future level of employment in the small establishments, the benefit margin of investment is reduced in small establishments. As a result, a low labor market matching rate holds back investments to be made by small establishments.

As productivity goes up, a stronger increase in investment rates in large establishments than in small establishments causes a decline of the relative marginal labor productivity in small establishments, compared to large establishments. The lower relative labor productivity in small establishments means that labor is more expensive to them. As a result, small establishments destroy more jobs. Although for a specific small establishment, it can create more jobs if it had a good chance to invest, but it can also destroy more jobs if it did not invest. The total change in job destruction depends on both the change of investment rates and the intensive margin of job destruction in establishments that do not invest.

The quantitative results show that the change in the intensive margin of job destruction dominates in the group of small establishments. Thus, their job destruction increases after the positive productivity shock. In the group of large establishments the change in investment rates dominates and job destruction decreases. Note that this comparison is conducted between two stationary equilibria, which means that the result represents what happens at the end of an expansion. The result indicates that job destruction in small establishments supports some of the job creation in large establishments when labor market is tight. This is consistent with the fact reported by Moscarin and Postel-Vinay (2008) that workers flow from small establishments to large establishments and wage accelerates during the late phase of an expansion.

7.1.2 Labor Search Model

A simple labor search model with heterogeneous establishments is constructed as follows. The establishments differ in their levels of productivity. The distribution of productivity is time invariant and the productivity of an establishment does not change over time. The establishments produce only with labor inputs. They hire workers subject to the labor market frictions. The productivity levels are chosen to generate a similar range of establishment sizes as in the benchmark model. The marginal disutility of working is set to 0.595 to ensure 6% unemployment in the initial stationary equilibrium. Other parameters are the same as in the benchmark model.

In the labor search model, after a 1% permanent positive productivity shock, both job creation and job destruction decrease dramatically in both small and large establishments.

Table 7.2 shows these responses of job creation and job destruction in small and large establishments. To avoid confusion I should remind the reader that job destruction is the sum of job losses of all the establishments that have reduced their numbers of workers. Job destruction differs from job separation in the current environment , but they are equal in a model where each establishment has only one job.

Table 7.2 Change in Job Creation and Destruction

Labor Search Model with Heterogeneous Establishments

Job creation		Job destruction	
Small	Large	Small	Large
−48.84%	−21.71%	−44.41%	−30.36%

Since it does not include capital, the model demonstrates pure labor market effects. The negative figures in table 7.2 mean that the turnover of jobs is low, but this is unrelated to the employment level. Table 7.3 shows that the employment level is higher after the shock. Also, more vacancies are posted and the vacancy-filling rate is low.

Table 7.3 Aggregate Conditions in the Labor Search Model

	Before shock	After shock
Lowest wage (A/p)	0.3960	0.3983
Unemployment rate	6.00%	5.39%
Vacancies / labor force	5.89%	6.36%
Vacancy-filling rate	0.5159	0.4834

The distribution of establishments spreads in two directions: productivity and employment. For any given level of productivity, there could be different levels of employment because of the random matching. After the shock, for a given level of establishment productivity, the mass of larger establishments tends to increase. As the establishments post vacancies more frequently to maintain a higher level of employment, they do not destroy many jobs.

Table 7.4.a The Distribution of Establishments before Shock - Labor Search Model

	Employment levels							
Productivity	-0.49	0.49-0.53	0.53-0.58	0.58-0.60	0.60-0.62	0.62-0.67	0.67-0.71	0.71+
0.460	0.0867	0.0498	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.477	0.0404	0.0575	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
0.493	0.0000	0.0348	0.1064	0.0051	0.0000	0.0000	0.0000	0.0000
0.510	0.0000	0.0000	0.0125	0.1175	0.0609	0.0055	0.0000	0.0000
0.526	0.0000	0.0000	0.0000	0.0000	0.0008	0.1501	0.0813	0.0000
0.543	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0950	0.0004

Table 7.4.b The Distribution of Establishments after Shock - Labor Search Model

	Employment levles							
Productivity	-0.49	0.49-0.53	0.53-0.58	0.58-0.60	0.60-0.62	0.62-0.67	0.67-0.71	0.71+
0.460	0.0925	0.0441	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
0.477	0.0102	0.0843	0.0035	0.0000	0.0000	0.0000	0.0000	0.0000
0.493	0.0000	0.0054	0.1265	0.0144	0.0000	0.0000	0.0000	0.0000
0.510	0.0000	0.0000	0.0036	0.0952	0.0933	0.0043	0.0000	0.0000
0.526	0.0000	0.0000	0.0000	0.0000	0.0017	0.1595	0.0710	0.0000
0.543	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0426	0.1478

Since it does not have lumpy capital, the labor search model cannot increase either job destruction or job creation in small establishments during expansion. In the benchmark model, the higher investment rates help to create more jobs. The boom in investment increases wages, destroying in turn the benefit margin of hiring in establishments that do not invest, and causing more job destruction in these establishments. Shutting down the lumpy capital margin reduces substantially the amount of worker flows among establishments.

7.1.3 Lumpy Capital Model

The lumpy capital model is built with a frictional capital market but a Walrasian labor market. Most of the parameters in this model are the same as in the benchmark model, but the marginal disutility of working A and the capital adjustment costs are adjusted so the unemployment rate is 6% and the size distribution of establishments resembles that in the benchmark model. Table 7.5 shows the changes in job creation and destruction in small and large establishments after a 1% permanent productivity shock. The model generates counterfactual predictions: job creation in large establishments does not increase, and job destruction increases in large establishments.

Table 7.5 Change in Job Creation and Destruction - Lumpy Capital Model

Job creation		Job destruction	
Small	Large	Small	Large
+1.31%	+0.00%	+0.00%	+2.44%

In the lumpy capital model, the changes in investment rates in small and large establishments after a productivity shock entail changes in job creation and job destruction. The reason is simple. Job creation comes from establishments that invest and hire to complement the increase in capital, and job destruction comes from establishments that do not invest and fire workers because of capital depreciation or lose workers because exogenous job-worker separation. After a 1% permanent positive productivity shock, the investment hazard rates in the group of small establishments increase more than those in the group of large establishments. On average, the investment hazard rates increase by 5.6% more in the group of small establishments in the lumpy capital model without labor search frictions. So the group of small establishments can increase its job creation by a higher proportion. If this increase in job creation in small establishments is very strong, it is possible that the small establishments steal workers from the large establishments. Thus, job creation in large establishments does not increase and job destruction in large establishments increases.

The aggregate amount of job destruction in each group of establishments depends on both the proportion of establishments that experience job destruction and the magnitude of that job destruction. Although the proportion of establishments that experience job destruction decreases in the group of large establishments, the magnitude of job destruction increases because of increased wages. The overall effect in the example is that job destruction increases in the group of large establishments. The increased job destruction is a result of relatively lower marginal labor productivity and relatively higher cost of workers. This abnormal response of large establishments is consistent with the literature on the augmented RBC models with real rigidities. This literature finds that the labor input tends to decline in response to a positive technology shock via strong wealth effects (see Francis and Ramey 2004, and Hashmat and Tsoukalas 2006).

7.2 Cyclicality and Volatility

The cyclical statistics generated by the benchmark model are shown in table 7.6. In this experiment, the magnitude of numbers is secondary compared with their sign. This is because the data is measured at the firm level, but the model works at the establishment level, and it assumes that the larger establishments belong to the larger firms. This is a strong assumption, although the empirical evidence shows a strong firm-establishment size correlation in general.

Table 7. 6 The Cyclical Statistics of Job Creation and Destruction

	Job creation		Job destruction	
	Small	Large	Small	Large
	Correlation with GDP			
Data	0.6192	0.4498	0.1815	−0.1781
Model	0.5324	0.3332	0.4222	−0.1230
	Relative standard deviation [12]			
Data	2.51	6.18	2.51	6.81
Model	6.20	4.64	5.08	4.82

In general, the cyclicality generated by the benchmark model is consistent with the data. The model performs best at matching the positive correlation between job destruction in small establishments and GDP. The model cannot generate the relatively smaller volatility found in small establishments. This is not surprising since in the real world small establishments face more risks, so they enter and exit more frequently even in good times[13], and this is not captured by the model. The more idiosyncratic the risks faced by small establishments (both during booms and busts), the smaller the volatility of their job creation and job destruction caused by the aggregate shock.

Besides changing investment hazard rates in the model, the random labor market search frictions have other effects on job creation and job destruction. First, they make the larger establishments destroy more jobs during recessions. The individual establishment job-filling rates are different even if all the establishments post the same number of vacancies. So random matching makes the establishment size distribution more dispersed. Specifically,

[12] The standard deviations of the variables are divided by the standard deviation of GDP.

[13] Davis, Haltiwanger and Schuh (1996) show that the exit rates of small firms are still high during expansion.

random matching makes establishments with an identical capital stock have different levels of employment. Among the establishments with the same capital stock, the larger ones are always more affected by a negative aggregate productivity shock. This contributes to the countercyclical job destruction in large establishments.

Second, the random labor matching makes some small establishments destroy more jobs during expansions. Random labor matching generates a group of establishments for which a larger size would optimal. However, they fail to hire enough workers and remain small on average. The establishments that fail to hire workers contribute to job destruction since, by assumption, all establishments are subject to an exogenous job-worker separations. This failure to hire enough workers is more likely to happen in booms, when the labor market is tight. This contributes to the procyclical job destruction in small establishments.

8 Concluding Remarks

The paper incorporates random labor market search frictions into a lumpy capital model in which capital adjustment is subject to idiosyncratic costs. In this model, the history of investment and labor market search outcome fully determines the sizes of firms. The same factor market frictions and uncertainties that generate the firm size distribution affect small and large firms differently. In such an economy, the aggregate productivity shocks are propagated through the frictional factor markets and, therefore, affect the employment dynamics in small and large firms asymmetrically.

By combining labor market search frictions and capital adjustment frictions, this paper finds that both the investment decision (investment hazard rate) and the intensive margin of investment depend on firm size. Moreover, the investment hazard rate in large firms responds strongly to positive aggregate productivity shocks. The labor market search frictions deter investment in marginal projects in small firms, especially when the labor market is tight. So the investment hazard rate in small firms does not increase as much as in large firms during booms. This generates a worker movement from small firms to large firms during booms, and contributes to the surprising procyclical job destruction in small firms.

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