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The cyclical behavior of job and worker flows*

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Job and worker flows in the U.S. and Europe have the following properties: Large and negatively correlated gross job creation and job destruction flows. Procyclical quits and countercyclical flows into and out of unemployment. Mortensen and Pissarides (1991, 1993) present a stochastic dynamic equilibrium model of labor market activity designed to explain these regularities. A parameterized and calibrated generalization of their model is studied here, one which incorporates search by employed workers. A demonstration that a single source of macro disturbance is consistent with the observed magnitudes of the comovements and fluctuations observed is the principal contribution of the paper.

Key words: Job creation; Job destruction; Beveridge curve; Quits

JEL classification: E24; E27; E32

1. Introduction

The study of worker flows to and from employment and among jobs has generated a considerable literature in the past twenty-five years. [See Devine and Kiefer (1991) for an extensive review of panel-based studies.] More recently, interest has broadened to include job flows, particularly those associated with job creation and job destruction. Worker and job flows, though not identical, are closely interrelated. The purpose of this paper is to report on and extend the efforts of Mortensen and Pissarides (1991, 1993) to develop and study a dynamic stochastic equilibrium framework for studying their interaction. The principal contribution is a demonstration that a calibrated version of their model with

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a single source of macro disturbance is consistent with a set of stylized facts concerning the cyclical behavior of labor market aggregates in both the U.S. and the major Western European industrial economies. These include: (i) a negative correlation between vacancies and unemployment, the well-known Beveridge curve, (ii) relatively large and negatively correlated gross job creation and job destruction flows, (iii) procyclical quits but countercyclical flows both into and out of unemployment. As a secondary contribution, a method of computing equilibria for a class of search equilibrium models is developed and applied in the paper.

The empirical regularity of longest standing is the Beveridge curve. A theoretical foundation for the concept arose out of search and matching theory [see Pissarides (1990)]. The basic idea is that the recruiting effort of employers and the search effort of workers serve as inputs in a market matching function that generates the flow of new hires. In the dynamic equilibrium, vacancies reflect recruiting effort and move in response to expectation about profitability. Given that the job–worker separation flow is roughly proportional to employment, the empirical Beveridge curve is the trace of observations generated by cyclical movements in expectations about the value of labor productivity and the tendency for unemployment to adjust to its conditional steady state [see Pissarides (1986) and of Blanchard and Diamond (1989)].

The recent creation of the LRD panel of establishments drawn from the U.S. Census of Manufacturing and similar panels in Europe has stimulated new research on gross job flows at the establishment and/or firm level. The cyclical properties of these flows for U.S. Manufacturing are documented by Davis and Haltiwanger (1990, 1992). They show that gross job creation, defined as the sum of all positive changes in employment across establishment, is procyclical and gross job destruction, the sum of the absolute value of all negative changes, is countercyclical. Furthermore, fluctuations in the latter are of larger amplitude than fluctuations in the former; two facts which together imply the sum, a measure of gross job reallocation, is countercyclical. Analogous studies for Germany [Boeri and Cramer (1991)], Italy [Contini and Revelli (1988)], and the U.K. [Konings (1993)] suggest similar empirical patterns.

To accommodate endogenous job destruction, Mortensen and Pissarides (1991) extend the matching equilibrium framework by allowing for heterogeneity in the value of product across jobs. Job destruction arises in the generalized model because the value of a specific match's product changes from time to time in response, say, to shifts in taste and technology. In particular, they assume that new jobs enter as the most productive but subsequently experience random changes in value of product. These assumptions are consistent with the idea that investment in employment opportunities associated with new technology and new products is essentially irreversible and, as a consequence, new jobs embody the best current information about future taste and technology. Given the specification, an endogenous decision to separate for the purpose of destroying the job exists. In the model, job creation depends positively and job destruction depends negatively on common expectations about future profitability.

Although Mortensen and Pissarides (1993) show that the simplest version of the (1991) version of their model can match the observed magnitudes of fluctuation found in U.S. Manufacturing job flow data, simulated job creation and job destruction flows are positively rather than negatively correlated with each other. The results reported in this paper suggest that this inconsistency can be attributed to the special assumption that employed workers do not share in match rent and consequently have no incentive to search while employed. Specifically, a version of the Mortensen and Pissarides model that incorporates employed worker search is studied. Simulations of the model's solution given appropriately calibrated parameter values imply that both a negative correlation between creation and destruction and more variable job destruction are consistent with it.

Job to job movements are a significant fraction of job separations and are procyclical in the U.S. as documented most recently by Akerlof, Rose, and Yellen (1989). The extended model is also consistent with these facts. Burda and Wyplosz (1990) have recently shown that both of these series are countercyclical in France, Germany, and the U.K. as well as in the U.S. The calibrated model studied in this paper implies positive correlations between both the flow of worker into and out of unemployment and the unemployment rate that are close in magnitude to those observed for the U.S. even though none of the parameter values are chosen for that purpose. As job creation and job destruction are identically equal to the flows out of and into unemployment otherwise, job to job movements induced by quits are essential to the explanation of these facts.

The organization of the paper follows. A model of the processes by which matches form, existing jobs die, and new jobs arise is sketched in section 2. The concept of an equilibrium solution to the dynamic labor allocation problem posed by the model is defined in section 3. Section 4 contains a method for computing a solution to a particular parameterized version of the model, and section 5 summarizes the equilibrium laws of motion that generate stochastic time series of interest. Reports of the results obtained by simulating a calibrated version of the model, and comparisons of the results with properties of job and worker flows data for the U.S. comprise section 6. An analysis of the effects on job and worker flows of variations in employed search activity and the workers' share of match surplus is reported in section 7.

2. Job creation, job destruction, and the matching process

The act of job creation is a decision by an employer to fill a vacant job at some cost. In equilibrium, the aggregate number of vacancies adjusts to eliminate any rent attributable to holding a job vacant. [See Pissarides (1986, 1990) for a complete development of this idea.]

Heterogeneity in job productivity is the principal innovation embodied in the Mortensen and Pissarides (1991) model. Specifically, newly created jobs are assumed more productive than existing jobs because, first, they can be located in either physical, technology, or commodity space to reflect current information about future profitability and, second, existing jobs and their worker occupants cannot be costly relocated. For example, one might imagine that a new job can be created on any one of many islands that compose the economy, that output on each island is affected by a persistent process which is not perfectly correlated across islands such as the weather, and that relocation of an existing matched worker and job together is not possible. In this world, new jobs will be located on the island expected to be the most profitable in the future conditional on current information.

Suppose that the net output at time t of a job–worker match is the sum of two components, $x_t + y_t$, where $\{x_t\}$ is a job-specific stochastic process and $\{y_t\}$ is an aggregate shock common to all jobs. Assume that the job-specific process is identical and independent across jobs, first-order Markov, and positively correlated with bounded support and that the aggregate shock is also first-order Markov and positively correlated. Under these assumptions, the expected present value of the future flow of profit attributable to a filled job is some generally increasing function of the pair of current values; denote this value of an occupied job to the employer as $J(x, y)$. Finally, all workers are equally productive by assumption.

The rate at which vacant jobs and searching workers match is determined by an increasing, concave, and homogeneous of degree one function $m(v, s)$, where v and s respectively represent the number of jobs that employers are attempting to fill and the number of workers seeking those jobs. Under the assumptions of random matching and constant returns, the probabilistic rate at which vacancies are filled is $m(v, s)/v = m(1, s/v)$. As the job expected to be most profitable in the future is that associated with the upper bound on x [provided that $J(x, y)$ is increasing in x], a free entry assumption implies that vacancies adjust to equate the expected return and cost of attempting to fill one, i.e.,

$$m\left(1, \frac{s(y)}{v(y)}\right) J(\gamma, y) = c_1, \tag{1}$$

where γ is the upper support of the job-specific component of productivity and c_1 is the cost of recruiting per period. Eq. (1) implicitly defines the equilibrium ratio of vacancies to searching workers, v/s, a measure of market tightness, as an increasing function of y, the current aggregate state. Because the rate at which searching workers find vacancies,

$$\alpha(J(\gamma, y)) = m\left(\frac{v(y)}{s(y)}, 1\right), \tag{2}$$

is an increasing function of market tightness, unemployment duration decreases in response to a positive aggregate shock.

Job destruction occurs when future profitability falls to the point where an existing match no longer has a positive expected present value. This zero profit condition implicitly defines a critical lower bound, denoted as $R_0(y)$, for the job-specific component of productivity conditional on the aggregate shock,

$$J(R_0(y), y) = 0\,. \tag{3}$$

As $J(x, y)$ is generally increasing in both its arguments, the reservation value of the idiosyncratic component is decreasing in y. Hence, job destruction can occur in two different ways: Either a new value of x, x', arrives and the new value $x' < R_0(y)$, or a new value of y, y', arrives and the old value $x < R_0(y')$.

To complete the characterization of job creation implicit in (1) and (2) and of job destruction suggested by (3), one needs the employer's value of a filled job function $J(x, y)$. Its specification depends on the nature of the wage contract and on worker search behavior. Following the matching literature and particularly its application to the labor market as characterized in Pissarides (1990), the wage is set to support a fixed split of the expected surplus capital value of the match between any specific employer and worker. Formally,

$$J(x, y) = (1 - \beta)S(x, y)\,, \tag{4}$$

where $S(x, y)$ represents the expected present value of the net product of a job–worker match characterized by the pair (x, y) and β is the fixed share of the surplus that the worker receives.

An employed worker searches whenever the expected return exceeds the cost. Let $W(x, y)$ represent the expected present value of a worker's future income given employment in a job characterized by the pair (x, y). As the value of employment in a vacant job is $W(\gamma, y)$ and the probability per period of finding a vacancy when searching is $\alpha(J(\gamma, y))$, the asset value of unemployment in aggregate state y, denoted as $U(y)$, solves

$$(r + \delta)U(y) = \max\{\alpha(J(\gamma, y))(W(\gamma, y) - U(y)) - c_2, 0\}. \tag{5}$$

Here r is the pure time rate of discount, δ is an exogenous rate of labor force turnover, and c_2 is the cost of search per period. As the surplus value of a match is $S(x, y) = J(x, y) + W(x, y) - U(y)$ by definition,

$$W(x, y) = \beta S(x, y) + U(y)\,, \tag{6}$$

by virtue of (4). Hence, the decision to search or not while employed, in order to maximize expected present value of future earnings $W(x, y)$, must maximize the joint surplus $S(x, y)$. Given search efficiency while employed equal to the parameter ζ, a worker maximizes joint surplus by searching if and only if the pair (x, y) lies below the boundary $x = R_1(y)$, where $R_1(y)$ equates the expected gain from search with its cost, i.e.,

$$\xi\alpha(J(\gamma, y))[W(\gamma, y) - W(R_1(y), y) - J(R_1(y), y)] = c_2 . \tag{7}$$

Under the simplifying assumptions made in this paper, quits also induce job destruction. This fact follows from the free entry condition embodied in eq. (1), the neglect of any sunk costs of creating a new job, and the assumption that newly created jobs are the most productive. Under these conditions, any job that a worker has an incentive to quit has negative value when vacant and, consequently, is destroyed.

3. The equilibrium surplus value of a match

In the case of a worker employed at a job with idiosyncratic component x, the expected present value of the worker's future income stream, $W(x, y)$, solves

$$\begin{aligned}(r + \delta) W(x, y) = {} & w(x, y) + \Phi(R_1(y) > x) \\ & \times [\zeta\alpha(J(\gamma, y))(W(\gamma, y) - W(x, y)) - c_2] \\ & + \lambda \int [\max(W(\tilde{x}, y), U(y)) - W(x, y)] \, \mathrm{d}F(\tilde{x}) \\ & + \eta \int [\max(W(x, \tilde{y}), U(y)) - W(x, y)] \, \mathrm{d}G(\tilde{y} \mid y) ,\end{aligned} \tag{8}$$

where $\Phi(z)$ is an indicator function equal to unity when condition z holds and to zero otherwise. The first term on the first line is the current state contingent wage received, while the second term is the expected capital gain associated with finding a vacancy given that search takes place only when the idiosyncratic component of productivity is less than the reservation value $R_1(y)$. The third line is the expected change in value of the worker's state associated with a possible arrival of a new job-specific productivity component, where λ represents the arrival rate of the process and F is the conditional cdf of the new value given arrival and the current value. (Note that independence across arrivals is assumed in the case of the idiosyncratic shock.) Finally, the last line is the expected change in the value of the worker's state attributable to the possibility that the common component of productivity changes, where η is the arrival rate and G is the conditional cdf of the new value. In sum, eq. (8) is a standard forward-looking asset pricing equation that defines the return on the asset value of being employed per period to be equal to current wage income plus the sum of expected capital gains and losses associated with events taking place during the period.

Similarly, the value of the same match to the employer involved, $J(x, y)$, is defined by

$$(r+\delta)J(x,y) = x + y - w(x,y) - \Phi(R_1(y) > x)\zeta\alpha(J(\gamma,y))J(x,y) + \lambda\int[\max(J(\tilde{x},y),0) - J(x,y)]\,\mathrm{d}F(\tilde{x}) + \eta\int[\max(J(x,\tilde{y}),0) - J(x,y)]\,\mathrm{d}G(\tilde{y}\,|\,y)\,. \tag{9}$$

The first line equals current profit less an allowance for the expected loss attributable to the possibility that the worker in the match quits. The second and final terms are the expected changes in the value of the employer's state associated with the possible arrival of a new job-specific and aggregate component of match productivity respectively.

By adding the corresponding sides of eqs. (8) and (9) and then subtracting the corresponding sides of eq. (5), one finds that eqs. (3)–(6) imply

$$[r+\delta+\lambda+\eta]S(x,y) = x + y - \max\{\alpha((1-\beta)S(\gamma,y))\beta S(\gamma,y) - c_2, 0\} + \max\{\zeta\alpha((1-\beta)S(\gamma,y)) \times [\beta S(\gamma,y) - S(x,y)] - c_2, 0\} + \lambda\int\max\{S(\tilde{x},y),0\}\,\mathrm{d}F(\tilde{x}) + \eta\int\max\{S(x,\tilde{y}),0\}\,\mathrm{d}G(\tilde{y}\,|\,y)\,. \tag{10}$$

The equilibrium surplus value of every possible match (x, y) is a solution $S(x, y)$ to the functional eq. (10). The associated equilibrium job creation, job destruction, and quit strategies are characterized by the vacancy finding rate $\alpha(J(\gamma, y))$ satisfying (1) and (2), the job destruction cut-off $R_0(y)$ that solves (3), and the search reservation value $R_1(y)$ implicitly defined by (7) given $J(x, y) = \beta S(x, y)$ and $W(x, y) = (1 - \beta)S(x, y) + U(y)$.

4. Solving the model

The aggregate shock process can always be approximated by a finite Markov chain with a sufficient number of states. In this case, a solution to the functional eq. (10) can be computed using the method sketched in this section. Let $i = 1, 2, \dots, n$ represent the aggregate state index, let y_i denote the value of the common productivity component in state i, and let η_{ij} be the rate at which the aggregate process transits from state i to state j. In this context, the surplus value of an occupied vacancy in aggregate state y, $S(\gamma, y) = P(y)$, as well as the reservation value functions, $R_0(y)$ and $R_1(y)$, are most conveniently represented as n vectors; denote them by $\boldsymbol{P}$, $\boldsymbol{R}_0$, and $\boldsymbol{R}_1$.

Given these three vectors, the right side of (10) divided by the term $r + \delta + \lambda + \eta$ is a contraction that maps the set of piecewise linear functions in x with $2n$ 'kinks' at values of x equal to the elements of $\boldsymbol{R}_0$ and $\boldsymbol{R}_1$ into itself. The solution method exploits this property as follows. First, the slopes of the surplus value function with respect to x between each pair of kink points are computed as solutions to a linear system of equations conditional on the unknown vectors $\boldsymbol{P}$, $\boldsymbol{R}_0$, and $\boldsymbol{R}_1$. Second, the first-stage results are used to formulate a system of $3n$ equations whose solution is the three n vectors $\boldsymbol{P}$, $\boldsymbol{R}_0$, and $\boldsymbol{R}_1$.

Let $b_i(x)$ represent the partial derivative of $S(x, y_i)$ with respect to x. By differentiating (10) with respect to x, one can show that the vector of slopes for every x not a kink point is the solution to the following linear system of n equations:

$$b_i(x) = \frac{1 + \sum_{k \neq i} \Phi(x \geq R_{0i}) \eta_{ik} b_k(x)}{r + \delta + \lambda + \zeta\alpha((1-\beta)P_i)\Phi(R_{1i} > x) + \sum_{k \neq i} \eta_{ik}}, \qquad i = 1, \dots, n, \tag{11}$$

where η_{ij} is the rate of transition from aggregate state i to j and $\Phi(z)$ is an indicator function equal to one when condition z holds and zero otherwise. Next, define the vector

$$\boldsymbol{a} = \operatorname{rank}\begin{pmatrix} \gamma \\ R_0 \\ R_1 \end{pmatrix}, \tag{12}$$

where rank (z) transforms the vector z by rearranging its elements in descending order. Finally,

$$\begin{aligned} S(x, y_i) &\equiv S_i(x, R_0, R_1, P) \\ &= P_i - \int_x^{\gamma} \frac{\partial S(z, y_i)}{\partial x} \mathrm{d}z \end{aligned}$$

$$= P_i + \sum_{j=1}^{2n} (x - a_{j-1}) b_i(x) \Phi(a_j \le x \le a_{j-1})$$

$$+ \sum_{j=1}^{2n} (a_j - a_{j-1}) b_i(a_j) \Phi(x < a_j), \qquad i = 1, \ldots, n, \tag{13}$$

is a representation of the surplus value function.

Of course, the elements of the reservation value vectors, $\boldsymbol{R}_0$ and $\boldsymbol{R}_1$ respectively, solve

$$S_i(R_{0i}, R_0, R_1, P) = 0, \qquad i = 1, \ldots, n, \tag{14}$$

by virtue of eqs. (3) and (4), and

$$\zeta\alpha((1-\beta)P_i)[\beta P_i - S(R_{1i}, R_0, R_1; P)] - c_2 = 0, \qquad i = 1, \ldots, n, \tag{15}$$

from eqs. (4), (6), and (7). The fact that no worker once employed in a vacancy searches and eq. (10) imply that the elements of $\boldsymbol{P}$ are determined by

$$P_i = \frac{y_i + \gamma - \max\{\alpha((1-\beta)P_i)\beta P_i - c_2, 0\}}{r + \delta + \lambda + \sum_{j \neq i} \eta_{ij}}$$

$$+ \frac{\lambda \int \max[S_i(x, R_0, R_1, P), 0]\, \mathrm{d}F(x) + \sum_{j \neq i} \eta_{ij} P_j}{r + \delta + \lambda + \sum_{j \neq i} \eta_{ij}}, \qquad i = 1, \ldots, n. \tag{16}$$

Eqs. (14), (15), and (16) form the desired system of $3n$ nonlinear equations.

The existence of an equilibrium solution can be established with the following argument. First, the right side of (11) is a contraction map defined on the set of positive, bounded, and real n-vectors for every x and $(\boldsymbol{R}_0, \boldsymbol{R}_1)$. Hence, it has a unique and strictly positive solution. Second, for fixed $\boldsymbol{R}_0$, $\boldsymbol{R}_1$, and $\boldsymbol{P}$, the form specified in (13) and the fact that the solution to (11) is strictly positive imply that (14) and (15) have unique solutions for R_{0i} and R_{1i} respectively for every i, which are both bounded above by the upper support of x and below by some finite number. Similarly, (16) has a unique finite solution for P_i for every i given $(\boldsymbol{R}_0, \boldsymbol{R}_1, \boldsymbol{P})$. As $S_i(x, \boldsymbol{R}_0, \boldsymbol{R}_1, \boldsymbol{P})$ is continuous in all arguments by virtue of eqs. (11)–(13), eqs. (14)–(16) implicitly define a continuous map from a bounded convex subset of $\boldsymbol{R}^{3n}$ into itself. Any fixed point, the existence of which is implied by Brouwer's theorem, is an equilibrium solution to the model.

5. The dynamics of job and worker flows

The dynamic laws of motion for employment and the associated worker flows implied by a solution to the model are made explicit in this section. For the purpose of characterizing dynamics, it is useful to think of time as divided into discrete periods. Let $t = 0, 1, \ldots$ represent the time index.

In order to describe the model's dynamics, one first needs to characterize the process that determines the number of workers employed in jobs with job-specific productivity between consecutive elements of the vector $\boldsymbol{a}$ defined in eq. (12) because occupied jobs in these different categories are generally subject to differential destruction risk. Let n_{it} represent the number of workers employed in jobs with idiosyncratic productivity in the half open interval $[a_i, a_{i-1})$, $i = 1, 2, \ldots$, at the end of period t. The distribution's law of motion is given by the system

$$n_{it+1} = \begin{cases} [1-\delta-\lambda]n_{it} + \lambda[F(a_{i-1}) - F(a_i)]\left[N_t - \sum_{a_j < R_0(y_t)} n_{jt}\right] \\ \quad \text{if} \quad \gamma > a_i \geq R_1(y_t) \\ [1-\delta-\lambda-\zeta\alpha((1-\beta)P(y_t))]n_{it} \\ \quad + \lambda[F(a_{i-1}) - F(a_i)]\left[N_t - \sum_{a_j < R_0(y_t)} n_{jt}\right] \\ \quad \text{if} \quad R_1(y_t) > a_i \geq R_0(y_t) \\ 0 \quad \text{if} \quad R_0(y_t) > a_i, \end{cases} \tag{17}$$

$$i = 1, 2, \ldots, n,$$

where N_t is the total employment measure at the beginning of the period and $P(y) = S(\gamma, y)$ is the value of an occupied vacancy because occupied jobs flow into the set defined by job-specific productivity interval i at rate $\lambda[F(a_{i-1}) - F(a_i)]$ and flow out at a rate equal to the sum of the quit rate and the job-specific component arrival rate. If reservation productivity in the current period is greater than productivity in the interval, then all jobs in the category are destroyed during the period. Note that the most productive jobs (i.e., the recently filled vacancies) are excluded from these categories. Hence, $N - \sum n_i$ is the measure of occupied jobs with $x = \gamma$.

In the empirical literature, the job creation (destruction) flow per quarter is the sum of all positive (negative) changes in employment over the individual establishments. As establishments are composed of single jobs and jobs that are quit are destroyed in the model, the creation flow is identical to the rate at which vacant jobs are matched with workers. It is useful to distinguish between the unemployed workers in the total and the employed workers who move to vacant jobs. Hence, letting C represent the job creation flow and Q denote the endogenous flow of workers moving from one job to another, the fact that each unemployed searching worker finds a vacancy with probability α implies

$$C_t = \alpha((1-\beta)P(y_t))(1-N_t) + Q_t, \tag{18}$$

and that each employed worker finds a vacancy with probability $\zeta\alpha$ implies

$$Q_t = \sum_i \zeta\alpha((1-\beta)P(y_t))\Phi(R_0(y_t) \le a_i < R_1(y_t))n_{it}, \tag{19}$$

where again $\Phi(z)$ is an indicator function equal to unity when condition z is true and to zero otherwise. Its presence in (19) accounts for the fact that workers employed in jobs destroyed at the beginning of the period cannot be also counted among the quits.

Jobs are destroyed for one of several reasons. Either the worker quits, the aggregate state worsens and the job's idiosyncratic component is now less than the new reservation value, or the job-specific component of productivity falls below the current reservation value. Assuming any new aggregate shock is realized at the beginning of the period, the total destruction flow attributable to these causes is

$$D_t = Q_t + \sum_{a_i < R_0(s_t)} n_{it} + [\delta + \lambda F(R_0(y_t))]\left[N_t - \sum_{a_i < R_0(y_t)} n_{it}\right]. \tag{20}$$

Obviously,

$$N_{t+1} = N_t + C_t - D_t \tag{21}$$

holds as an identity. In the sequel, the lower case letters, c, d, and q, represent job creation, job destruction, and quit rates per employed worker respectively, where the measure of the employed labor force used to normalize is the average of the beginning and ending stocks. Finally, flows into and out of unemployment per employed worker are represented by $In = d - q$ and $Out = c - q$.

6. Calibrating and simulating the model

The aggregate shock is modelled as a three-state Markov chain. The state-to-state transition matrix is assumed to have the following structure:

$$H = [\eta_{ij}] = \begin{bmatrix} \Psi & \Gamma & 1-\Psi-\Gamma \\ \varphi & 1-2\varphi & \varphi \\ 1-\Psi-\Gamma & \Gamma & \Psi \end{bmatrix}, \tag{22}$$

and the three values of the aggregate shock are elements of the ordered set $\{\mu - z, \mu, \mu + z\}$. This specification has a Wold representation [see Christiano (1990)] for $\{y_t\}$ of the form

$$y_t = \rho y_{t-1} + (1 - \rho)\mu + v_t, \tag{23}$$

where

$$\mathrm{E}v_t y_{t-1} = \mathrm{E}v_t = 0, \qquad \mathrm{E}v_t^2 \equiv \sigma_v^2 = \frac{z^2(1 - \rho^2)}{\kappa},$$

$$\rho = 2\Psi + \Gamma - 1, \qquad \kappa = 1 + 0.5\frac{\Gamma}{\varphi}.$$

In the simulations that follow, the time period is a quarter, the correlation coefficient $\rho = 0.933$ per quarter, the standard deviation of the innovation $\sigma = 0.011$ per quarter, $\Gamma = 0.067$, and kurtosis $\kappa = 3$ as in the case of the normal. The autocorrelation coefficient and the innovation variance assumed are estimates obtained over the post-war period using deviations of the log of manufacturing productivity per hour from trend as a measure of the aggregate productivity shock. The implied value of the aggregate shock is $z = 0.053$ and that of the transition probability matrix is

$$H = \begin{bmatrix} 0.933 & 0.067 & 0.000 \\ 0.017 & 0.967 & 0.017 \\ 0.000 & 0.067 & 0.933 \end{bmatrix}. \tag{24}$$

As a normalization, the baseline mean value of the aggregate component was set so that the job destruction reservation value was roughly equal to zero in the intermediate aggregate state, i.e., $R_0(\mu) \approx 0$, given the other parameter values.

The distribution of idiosyncratic shock, F, is taken to be uniform with zero mean and range $[-\gamma, \gamma]$. Hence the 'normal' rate at which jobs are destroyed in the absence of any change in the common component of productivity is $\lambda[\gamma + R_0(y)]/2$. The matching function used is log-linear with elasticity with respect to search effort equal to θ. Given this form, eqs. (1) and (2) yield the following representation of the rate at which searching workers find vacancies:

$$\alpha((1 - \beta)P) = A\left[\frac{(1 - \beta)P}{c_1}\right]^{(1-\theta)/\theta} = k[(1 - \beta)P]^{(1-\theta)/\theta}, \tag{25}$$

where A is the scale parameter of the matching function and k is the implied scale parameter of the vacancy finding function.

Table 1

Baseline parameter values.

$\rho = 0.933$	Macro shock autocorrelation	$r = 0.01$	Pure discount rate
$\sigma = 0.011$	Macro innovation saddle	$\delta = 0.005$	Exogenous turnover rate
$\lambda = 0.067$	Idiosyncratic shock arrival rate	$\beta = 0.5$	Worker's share of match surplus
$\gamma = 0.029$	Idiosyncratic upper support	$\theta = 0.5$	Search elasticity of matching
$\mu = 0.052$	Mean productivity	$k = 5$	Finding rate scale parameter
$\zeta = 0.20$	Employed search intensity	$c_2 = 0$	Search cost

The value of an occupied vacancy and the cut-off and reservation job-specific productivity values in each aggregate state were computed using the method sketched in section 4. The baseline parameters used, reported in table 1, were set as follows: The discount rate $r = 1\%$ per quarter, a value that reflects historical real interest rates. The symmetric bargaining outcome, $\beta = 0.5$, was assumed simply because no direct evidence on match value sharing is currently available and one-half is the solution in the case of a symmetric bargaining game. The search elasticity of the matching function, θ, used is also 0.5, which is midway between the estimate obtained by Blanchard and Diamond (1989) using U.S. data and that of Pissarides (1986) for the U.K. Calculations based on the National Longitudinal Survey of Mature Men reported in Akerlof et al. (1988) were combined with Davis and Haltiwanger (1992) job destruction statistics to set both the exogenous turnover rate δ and to help calibrate the other parameter values. The NLS data imply that 37% of all job separations are quits and that 77% of these involve job-to-job transition without unemployment. As the quarterly estimate of the job destruction rate for the 1972–88 period was 5.5%, the implied exogenous turnover rate and endogenous quit rate are approximately $\delta = 0.5\%$ and $q = 1.55\%$ per quarter.

Given the other parameters, the arrival rate of the idiosyncratic component, λ, was determined to approximately equate the model's mean job creation rate with that of U.S. Manufacturing data, the idiosyncratic distribution range parameter, γ, was determined to match the second moment of the reported job creation rate series, and the search intensity of employed workers, ζ, was set so that the average endogenous quit rate would equal the computed estimate of 1.55%. The scale parameter, k, was chosen to obtain a rough match of the model's unemployment rate with the average for the U.S. during the same period and, for lack of direct evidence, search cost were set at zero. Finally, the mean probability parameter μ was selected so that all jobs in the best aggregate state are just viable.

The calibration restrictions have interesting implications for the parameters they determine. The autocorrelation in the job-specific productivity process is $1 - \lambda = 0.933$, while the range, $\gamma = 0.029$, is approximately equal to the

Table 2

Baseline simulation results: Means (standard errors) of 100 samples.

	Simulation statistics	Data
Mean(c)	5.20[a] (0.35)	5.2[b]
Stdev(c)	0.92[a] (0.39)	0.9[b]
Stdev(d)	1.50 (0.66)	1.6[b]
Corr(c, d)	− 0.12 (0.37)	− 0.36[b]
Mean(q)	1.55[a] (0.46)	1.55[c]
Corr(v, u)	− 0.47 (0.33)	− 0.88[d]
Corr(q, u)	− 0.77 (0.29)	− 0.74[e]
Corr(In, Out)	0.10 (0.33)	0.16[f]
Corr(In, u)	0.72 (0.34)	0.91[f]
Corr(Out, u)	0.56 (0.30)	0.42[f]
Mean(u)	6.87[a] (2.46)	6.87[f]

[a] Parameters set to match model and data moments.
[b] U.S. Manufacturing job flow series, 1972.2–1988.4, Davis and Haltiwanger (1992).
[c] Computed as per text.
[d] Merz (1992).
[e] Akerlof et al. (1988).
[f] Computed from U.S. unemployment and unemployment duration statistics, 1972.2–1988.4.

standard deviation of the ergodic distribution of the aggregate shock, which is $\sigma/\mathrm{sqrt}(1-\rho^2) = 0.031$. Hence, both results are consistent with the microeconomic evidence for substantial and persistent heterogeneity reported by Davis and Haltiwanger (1992). Finally, an employed worker search intensity of 0.20 suggests that the efficiency of employed worker search is much less than when unemployed.

The moments and cross-correlations obtained by simulating the model with parameters set at baseline values are reported in table 2. The statistics are means (with standard deviations in parentheses) obtained by averaging over 100 simulated samples, each 66 quarters in length. Sample statistics primarily for U.S. Manufacturing data on job creation and job destruction and U.S. unemployment stock and flow data over the 66 quarters from 1972.II to 1988.IV are reported for comparison. Of course, the first and second moments of the job destruction series are roughly equal to the model's values because the two were matched for the purpose of parameter calibration. Although the model implies considerable sample variation when the observation period is only 66 quarters in length, observations on both the correlation between job creation and job destruction and the relative magnitudes of their variability are consistent with the model's implications. Specifically, the observed correlation between the two series, -0.36, is well within one standard deviation of the model's mean over the hundred simulations, -0.12 ± 0.37. Furthermore, the observed standard deviation of the job destruction rate, 1.6, is statistically indistinguishable from the model's mean of 1.5 given that the standard deviation across the 100 samples is 0.66. Although the model implies that job destruction is substantially more volatile than job creation, the large standard errors associated with the two simulated series also imply that observed equality is not unlikely in a sample period of 66 or fewer quarters.

Table 2 also provides evidence that the model is consistent with the principal stylized facts about worker flows. For example, the model predicts both a Beveridge curve and procyclical quits. The positive correlation of the flows in and out of unemployment with one another and with unemployment observed in U.S. data are also well explained by the model.

Although virtually all the means generated by the model are close to the value of the statistic found in the data, the standard errors implied by the model are very large. In short, the model predicts considerable sample variation when the sample size is only 66 quarters. Indeed, under the null hypothesis that the model generates the data, observed positive correlation between either creation and destruction or between vacancies and unemployment would not be surprising in a single sample 66 quarters in length. Whether these large standard errors might be a consequence of the crude three-state approximation to the aggregate shock process is an issue addressed in future research.

Figs. 1 and 2 illustrate the responses in the job creation, job destruction, and quit rates to changes in aggregate state implied by the model given the baseline parameters. The responses in each quarter following a transition from the intermediate to the highest macros state are illustrated in fig. 1, while the responses to a transition from the intermediate to the worst macro state are illustrated in fig. 2. As the absolute size of the productivity disturbance, z, is the same in both cases, the two figures clearly illustrate why job destruction is more variable than job creation in the model. The asymmetry is primarily a consequence of the fact that time is required by the matching process to adjust employment upward in response to the positive shock, but job destruction takes place almost instantaneously after new information arrives.

The fact that job creation initially falls in response to a negative aggregate shock, but then rebounds and overshoots before adjusting smoothly to its new equilibrium level is another interesting difference between the two adjustment paths illustrated in figs. 1 and 2. This behavior can be attributable to the fact that workers search less when employed than when unemployed and the assumption that search workers and vacancies are complements in the matching technology. Specifically, the sharp initial rise in job destruction immediately after the realization of the shock changes the status of a significant fraction of the work force from employed to unemployed. As the intensity of search while unemployed is five times larger than when employed, the effective number of searching workers and the job creation rate increase as a consequence. This property of the model seems to be reflected in the time series for

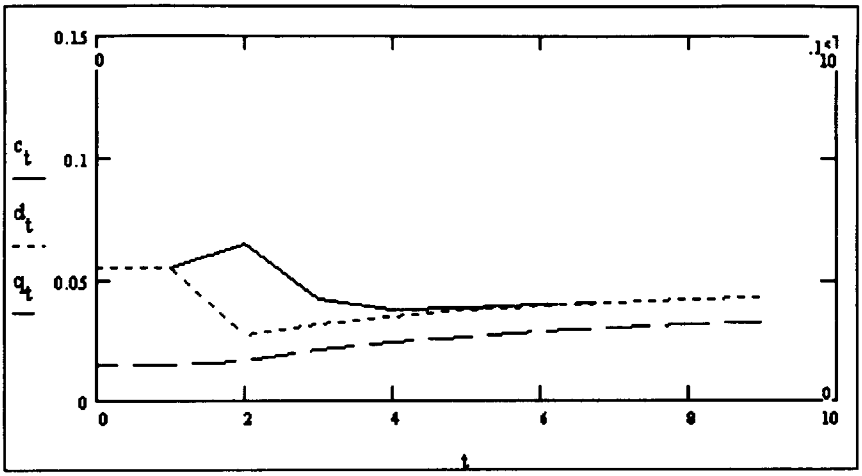

Fig. 1. Adjustment paths, positive aggregate shock.

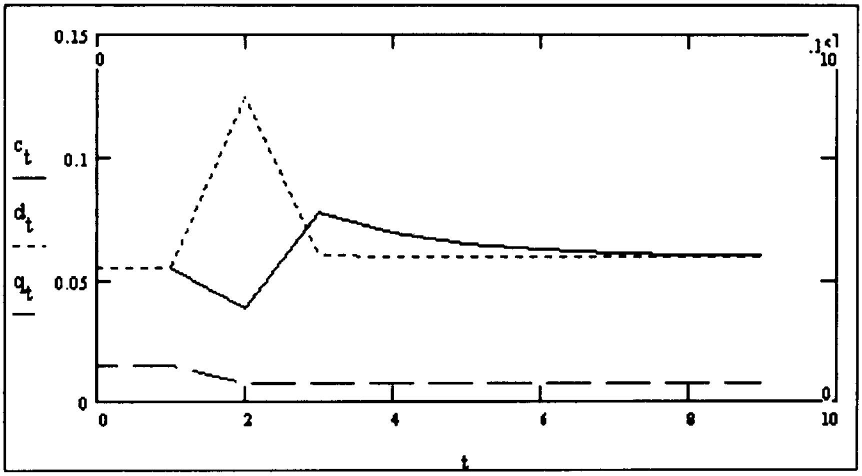

Fig. 2. Adjustment paths, negative aggregate shock.

U.S. Manufacturing illustrated in fig. 3, at least in some instances. Note the overshooting following a spike in job destruction in late 1975 and again in 1981 and 1983 after subsequent negative shocks.

Fig. 4 is a particular sample plot of job creation, job destruction, and quit rates over one 66-quarter interval obtained in simulating the model. Although

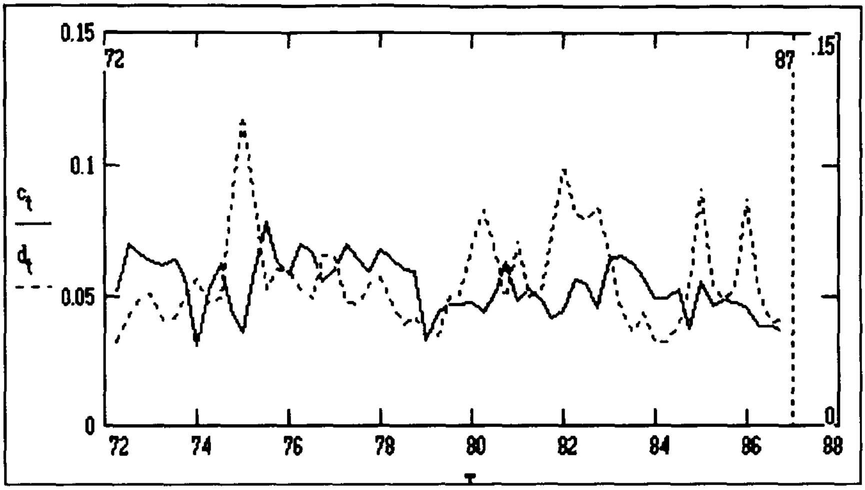

Fig. 3. U.S. manufacturing, *source*: Davis and Haltiwanger (1993).

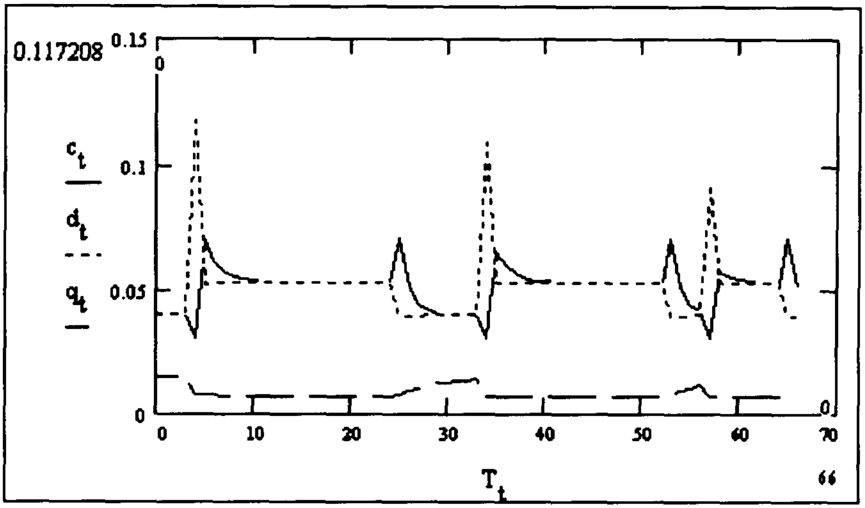

Fig. 4. Example simulated time series.

rather stylized, the model's series illustrates the overshooting of job creation noted in figs. 1 and 2. The plot also provides a graphic demonstration that the model implies procyclical movement in quits. The quit series, designated in the figure by the long dashes, rises after each positive shock and falls in response to

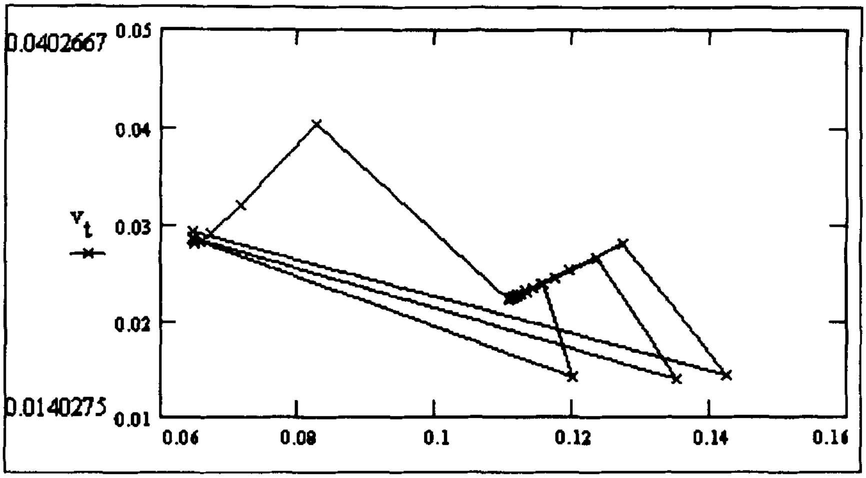

Fig. 5. Example simulated Beveridge curve.

negative shocks. The Beveridge curve traced out by this same sample of 66 quarters is illustrated in fig. 5. Note that each spike in job destruction is associated with a rapid drop in vacancies and a subsequent increase in unemployment. In turn, vacancies rebound slightly in response to the subsequent increase in search effort, resulting in a small decrease in unemployment. However, full recovery in the number of vacant jobs only occurs in response to a eventual positive aggregate shock. These response patterns captured by the model imply the characteristic countercyclical loops in vacancy–unemployment space.

The sample plot in fig. 4 also illustrates that a jump in job destruction induced by a negative shock is bigger the longer is the preceding period of relative prosperity. To see this point, note that two identical positive shocks occur during the period, each followed by a downturn in productivity. However, the length of time between the first positive shock and the subsequent downturn is longer than the period between the second upturn and the negative shock that followed it. Since a larger number of relatively less efficient jobs were accumulated during that longer first interval, the fraction of jobs destroyed at the end was larger in the first case than in the second. This example suggests that the model's propagation mechanism can produce quite complicated time series patterns even when the forcing process inducing fluctuations is very simple and stylized.

7. The effects of employed search intensity and workers' share of surplus

A comparison of the results obtained in the illustrative simulation reported in Mortensen and Pissarides (1993) with the results reported in table 2 suggests that the model's equilibrium statistical properties are sensitive to either or both the intensity with which employed workers search and the workers' share of surplus. Specifically, when workers do not share in match surplus ($\beta = 0$) and as a consequence employed worker do not search ($\zeta = 0$) as assumed in the illustrative simulation presented in the earlier paper, job creation and destructive are positively correlated, contrary to fact. The following question arises: Is the negative correlation reported in table 2 a consequence of relaxing the no employed worker search assumption or the assumption that workers do not share in the surplus?

The theoretical consequences of either more employed search or a large worker share of surplus on the equilibrium properties of the model are difficult to determine. Obviously, the more employed workers search, the smaller the role of job destruction in the reallocation of labor input from less to more productive activity. However, employed search also affects the incentives to create and destroy jobs, essentially by reducing the expected length of life of any match. Guessing the signs of cross-effects of employed search and the aggregate shock is beyond the author's intuitive feel for the model's structure. Similarly, an increase in worker share stimulates employed worker search but reduces employer incentives to create vacancies.

One way to obtain some sense of the potential sign and magnitude of parameter effects is to simulate them. The effects of variation in the search intensity of employed workers on the simulated job and worker flow statistics are reported in table 3. The table contains averages of the various statistics over 100 simulated samples of 66 quarters, each of five different values of the search intensity parameter centered at the baseline value. Table 4 is an analogous table of results for the effects of different values of the workers' share of match surplus.

Since the correlation between job creation and job destruction is negative for all values of the search intensity parameter considered in table 3, the assumption of no search by employed is not responsible for the implied positive correlation reported in Mortensen and Pissarides (1993). However, the response to increases in intensity is nonmonotonic, reflecting the highly nonlinear nature of the model.

Several authors have emphasized the 'crowding-out' effect of an increase in employed worker search on the finding probability of unemployed workers. [See Burgess (1991) and Pissarides (1991).] Specifically, given the number of vacancies, an increase in employed search intensity extends the duration of unemployment for all. However, the complementarity between vacancy seeking workers and worker seeking vacancies present in the log-linear matching function assumed and the free entry condition (1) imply that vacancies respond in proportion to offset congestion of this kind. For this reason and because quits displace layoffs as a source of job destruction, the unemployment rate falls with search by unemployed workers, as is clearly documented in the last line of the table. Note that the volatility of both creation and destruction also falls substantially with employed search intensity.

Table 3

The effects of employed worker search intensity.

$\zeta =$	0	0.1	0.2	0.3	0.4
Mean(c)	5.15	5.18	5.20	5.22	5.25
Stdev(c)	0.99	0.94	0.92	0.83	0.69
Stdev(d)	1.57	1.51	1.50	1.39	1.19
Corr(c, d)	− 0.16	− 0.10	− 0.12	− 0.17	− 0.21
Mean(q)	0.0	0.78	1.55	2.26	2.88
Corr(v, u)	− 0.39	− 0.44	− 0.47	− 0.55	− 0.66
Corr(q, u)	0.0	− 0.71	− 0.77	− 0.81	− 0.84
Corr(In, Out)	− 0.16	− 0.03	0.10	0.20	0.26
Corr(In, u)	0.63	0.68	0.72	0.75	0.76
Corr(Out, u)	0.38	0.48	0.56	0.61	0.65
Mean(u)	9.15	8.03	6.87	5.78	4.79

Table 4

The effects of workers' share.

$\beta =$	0.2	0.35	0.5	0.65	0.8
Mean(c)	4.72	5.10	5.20	5.12	4.76
Stdev(c)	1.45	1.05	0.92	0.87	0.87
Stdev(d)	1.56	1.41	1.50	1.71	2.14
Corr(c, d)	0.13	− 0.01	− 0.12	− 0.20	− 0.23
Mean(q)	1.45	1.52	1.55	1.55	1.53
Corr(v, u)	− 0.32	− 0.42	− 0.47	− 0.47	− 0.42
Corr(q, u)	− 0.36	− 0.61	− 0.77	− 0.86	− 0.90
Corr(In, Out)	0.20	0.17	0.10	0.04	− 0.04
Corr(In, u)	0.87	0.80	0.72	0.64	0.53
Corr(Out, u)	0.28	0.48	0.56	0.62	0.69
Mean(u)	3.39	5.13	6.87	8.89	11.54

The effects of increasing worker share, β, on the equilibrium statistics are illustrated in table 4. Here we find that the correlation between job creation and job destruction is positive for small values, and then reverses sign and becomes larger in absolute value as worker share increases. Hence, the counterfactual positive sign reported for the simulation in Mortensen and Pissarides (1993) can be attributed to the assumption that workers don't share surplus rather than the assumption that employed workers don't search.

An increase in the worker's share of match surplus increases the return to worker search but reduces the employer incentives to create vacancies. The fact that the mean unemployment rate rises with worker share suggests that the demand effect dominates in the case at hand. In short, employment is adversely affected by worker bargaining power and indeed the results reported in fig. 4 suggest that quantitative size of the effect is quite large.

Although unemployment rises with worker share, a zero share is not socially optimal. The existence of search externalities that induce equilibrium behavior different from that which maximizes the expected present value of aggregate output has been recognized for some time. In the case at hand, a result proved by Hosio (1990) implies that the equilibrium of the model studied here solves that social welfare problem if and only if the workers' surplus share is equal to the elasticity of the matching function with respect to search input. This condition, $\beta = \theta$, holds by assumption in the baseline simulation. Hence, unemployment rates associated with values of the workers' share less than 0.5 are 'too-low' because the sharing rule induces 'over-investment' in employer recruiting activity.

7. Summary

The demonstration that an extended version of the Mortensen and Pissarides (1991, 1993) model, one that incorporates employed worker search, is consistent with a large set of stylized facts concerning the cyclical behavior of labor market flows and aggregates in the U.S. and several Western European economies is the principal contribution of the paper. The phenomena explained by the model include: (i) the negative correlation between vacancies and unemployment, the Beveridge curve, (ii) the large magnitudes of gross job creation and job destruction flows and their negative correlation, (iii) the procyclical behavior of quits and the countercyclical movements in both the flows into and out of unemployment. The program used to solve the model and to compute the simulations reported in this paper is available from the author.

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