DISCUSSION PAPER SERIES

No. 5459

SEARCH AND MATCHING IN MACROECONOMICS

Eran Yashiv

INTERNATIONAL MACROECONOMICS and LABOUR ECONOMICS

Centre for Economic Policy Research

www.cepr.org

Available online at: **www.cepr.org/pubs/dps/DP5459.asp**

ISSN 0265-8003

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Eran Yashiv, London School of Economics (LSE) and Tel Aviv University and CEPR

Discussion Paper No. 5459
January 2006

Centre for Economic Policy Research
90–98 Goswell Rd, London EC1V 7RR, UK
Tel: (44 20) 7878 2900, Fax: (44 20) 7878 2999
Email: cepr@cepr.org, Website: www.cepr.org

CEPR Discussion Paper No. 5459

January 2006

ABSTRACT

Search and Matching in Macroeconomics*

This paper surveys the use of search and matching models in macroeconomics. It outlines the standard model, discusses its extensions, presents alternative formulations, considers the empirical evidence, and studies applications to macroeconomic questions such as business cycles, growth, and policy. Particular attention is given to the ability of the model to account for labour market dynamics and for cyclical fluctuations in aggregate economic activity

JEL Classification: E24, E32, E52, J23, J31, J41, J63, J64 and J65
Keywords: business cycles, growth, macroeconomics, matching, policy, search and worker flows

Eran Yashiv
Department of Economics (S680)
London School of Economics
Houghton St.
London
WC2A 2AE
Tel: (44 20) 7955 7584
Fax: (44 20) 7955 6592
Email: E.Yashiv@lse.ac.uk

*I am grateful to Darina Waisman for research assistance. Any errors are my own.

Submitted 03 January 2006

Search and Matching in Macroeconomics[1]

1 Introduction

The search and matching model has gained much attention in macroeconomic analysis. This survey aims at providing an exposition of the model as used in macroeconomics and an up-to-date discussion of key macroeconomic issues that are explored using this model.

The model highlights frictions in the labor market – the processes of search and matching – to account for dynamics and for the determination of all key outcomes. It emphasizes the flows between labor market states – employment and non-employment – and allows for a dynamic steady state. Like other key models in macroeconomics, it features optimizing agents, rational expectations, and equilibrium outcomes. These features allow it to be readily used in other such frameworks like RBC, New Keynesian, and growth models.

A major reason for the use of the model in macroeconomics stems for the fact that it provides a rich framework for the analysis of aggregate fluctuations. Hall (2003) notes that "the idea that trading frictions play an important role in shaping aggregate labor market outcomes has become increasingly standard over the past years. The early work of Peter A. Diamond, Dale Mortensen, and Christopher Pissarides has spawned a class of models that have become the standard in formalizing these trading frictions." Rogerson (1997) describes it as a modern theory of unemployment that caters well for labor market dynamics and that has proved useful in accounting for the time series behavior of aggregate unemployment.

As an expression of its enhanced use in macroeconomics, it is interesting to note that as recently as the early 1990s the model was absent from most macroeconomic textbooks. Now it is increasingly used; see, for example, the undergraduate textbook of Mankiw (2003, 5th edition, Chapter 6) and the graduate textbooks of Ljungqvist and Sargent (2004, 2nd edition, Chapter 26) and Romer (2006, 3rd edition, Chapter 9.8).

[1] I am grateful to Darina Waisman for research assistance. Any errors are my own.

The paper proceeds as follows. Section 2 presents the standard model. It starts from the basic elements, goes on to characterize its equilibrium and dynamics, embeds it into a general equilibrium model, and presents the conditions for efficiency. It ends with a description of the history of the development of the model in the literature. Section 3 goes deeper: it presents the major extensions and modifications that have been proposed. While Sections 2 and 3 are theoretical, Sections 4 and 5 deal with empirics. Section 4 describes the data relevant for the examination of the model, discussing at some length the measurement and interpretation of gross worker flows. It then describes key papers which have estimated the model. This leads naturally to the discussion, in Section 5, of the contribution of the model to the study of business cycles. The latter includes a discussion of recent controversies and debates. Section 6 then takes up, more briefly, the role of the model in the study of other macroeconomic questions: growth, inequality, and policy. Section 7 is a short discussion of the link with other search models, particularly the micro-based literature. Section 8 offers a summary of open questions and concludes.

A remark about the relation of this survey to other surveys and studies is warranted. The recent survey by Rogerson, Shimer and Wright (2005) characterizes three main classes of search models: random matching and bargaining, directed search and wage posting (following Moen (1997)), and random matching and wage posting (two key models of the latter class and many references are discussed in their Section 6). The current survey refers to the first class of models, exploring macroeconomic implications. It updates and greatly expands the discussion contained in the survey by Mortensen and Pissarides (1999a), covering the mileage made in the eight or so years since the writing of the latter. It complements, but does not overlap, the surveys of the micro-based search literature by Mortensen (1986), Mortensen and Pissarides (1999b), and Eckstein and van den Berg (2005). Finally, Pissarides (2000) provides an excellent overview of the basic model and its main extensions, as well as comments on the literature. The current survey, beyond discussing the basic model, does not replicate the discussion there. As in other such surveys, it is impossible to cover all of the relevant contributions, so the outcome is a selective review of the literature.

2 The Standard Model

In this section I briefly sketch out the standard model. The presentation closely follows Pissarides (2000, in particular Chapters 1-3) and, for the most part, uses his notation.[2] I start with the general set up. I then specify the dynamics by formulating the matching or hiring flow and the separation flow. Next I consider the optimization decisions of firms and workers which determine their search activity. Subsequently I derive the wage solution. I proceed to characterize the equilibrium in steady state, its embedding in a general equilibrium framework, and its efficiency. I end by discussing the chronological development of the model.

2.1 The Environment

There are risk-neutral, infinitely-lived workers and firms. There are many such agents so each operates as an atomistic competitor; formally this is often modelled as a continuum on a closed interval. Agents discount the future at rate r and have rational expectations. Firms and workers need to engage in costly search to find each other. Firms spend resources on advertising, posting job vacancies, screening, and, subsequently, on training. Workers spend resources on job search, with costs pertaining to activities such as collecting information and applying to jobs. Workers and firms are assumed to be randomly matched. After matching, the worker and the firm engage in bilateral bargaining over the wage.

The basic model essentially relates to homogenous workers and homogenous jobs, so unemployed workers seek identical job vacancies. More complicated versions introduce heterogeneity with workers of different skills or preferences, with jobs of various qualities (such as 'good' and 'bad' jobs), or with ex-post heterogeneity in matching. This opens the way to on-the-job search and job-to-job movements. In what follows I shall first refer to the more basic model before considering various extensions.

[2] The key papers underlying this model are Diamond (1982a,b), Mortensen (1982a,b), Pissarides (1979, 1985), and Mortensen and Pissarides (1994). See sub-section 2.12 below.

2.2 Modelling Variations

The basic model has been formulated using a number of variants, which I briefly spell out, before proceeding to the formal exposition.

First, the model can relate to a one firm-one job set up (as in Pissarides (2000), Chapters 1 and 2) or to large firms (as in Chapter 3 of Pissarides (2000)). In the latter case the assumptions are that the firm employs many workers, and that on average it is large enough to eliminate all uncertainty about the flow of labor. Even in this set up the wage is given by a bargain at the individual level. Wages are set as though the firm engages in bargaining with each worker separately, taking the wages of all other workers as given. In deciding how many job vacancies to open the firm anticipates the wage correctly but takes it as given. I will follow the latter course here.

Second, the model may be set in non-stochastic or stochastic terms. The latter typically allow for shocks to productivity, to the matching function, and to the rate of match dissolution (or worker separation from jobs). In what follows I shall set out the basic model in non-stochastic terms and later refer to stochastics wherever relevant.

Third, the model may be formulated in continuous time or in discrete time, whereby the timing of matching and production is important. The former is presented, for example, in Pissarides (2000), while the latter is presented, for example, in Yashiv (2004). Here I shall use the continuous time formulation.

2.3 Job-Worker Matching

Unemployed workers (denoted u in terms of rate out of the labor force) and job vacancies (denoted v in the same terms) engage in matching. The latter process is formalized by a 'matching function' that takes searching workers and vacant jobs as arguments and produces a flow of matches. It assumes frictions in the matching process such as informational or locational imperfections. As noted by Pissarides (2000, page 4) "the matching function summarizes a trading technology between heterogeneous agents that is not made explicit."

The matching function is given by:

$$m = m(u, v). \tag{1}$$

It is continuous, non-negative, increasing in both its arguments, and concave. Typically it is assumed to be homogeneous of degree 1. If we allow for worker search intensity s this will become:

$$m = m(su, v) \tag{2}$$

For simplicity I shall normalize aggregate search intensity at $s = 1$. Its determination by the worker will be discussed below.

It is useful to define a concept of 'market tightness,' given by the vacancy-unemployment ratio v/u, to be denoted by θ. Using the homogeneity assumption, the vacancy matching rate q is given by:

$$q(\theta) \equiv \frac{m}{v} \equiv m\left(\frac{u}{v}, 1\right). \tag{3}$$

where $q'(\theta) \leq 0$.

Unemployed workers move into employment with a job finding rate, or hazard rate, given by:

$$p(\theta) \equiv \frac{m}{u} \equiv \theta q(\theta) \tag{4}$$

where $p'(\theta) \geq 0$.

The dependence of the rates $q(\theta)$ and $p(\theta)$ on market tightness is an expression of the externalities inherent in the model. These are search and congestion externalities: more agents searching on the same side cause a negative congestion externality, while more agents searching on the other side cause a positive trading externality.

2.4 Match Separation

The flow into unemployment results from job-specific (or idiosyncratic) shocks to matches that arrive at the Poisson rate λ. These shocks may be explained as shifts in demand (that change the relative price of the good produced by a job) or by productivity shocks (that change the costs of production). Once a shock arrives, the firm either continues production at the new value or closes the job down.

In the earlier version of the model (for example, Pissarides (1985)) the arrival of a shock leads to the closing down of the job, i.e., the dissolution of the match and to worker separation. Thus idiosyncratic shocks move the value of the match output from a high level to a low one, at which it is not profitable to operate, at the exogenous rate λ.

In the later version of the model (see Mortensen and Pissarides (1994)), the arrival of an idiosyncratic shock makes the net product of the job change to some new value that is drawn from a general probability distribution, not necessarily closing down the job. The job destruction decision (and thus the value of λ) becomes endogenous. I return to this point below.

2.5 Unemployment Dynamics and Steady State

The evolution of the unemployment rate is given by the difference between the separation flow and the matching flow:

$$\dot{u} = \lambda(1-u) - p(\theta)u. \tag{5}$$

In the steady state rate of unemployment is constant and given by:

$$u = \frac{\lambda}{\lambda + p(\theta)}. \tag{6}$$

This is a key equation of the model. It can be represented in tightness (θ) – unemployment (u) space or in vacancy (v) – unemployment (u) space, by a downward-sloping curve, known as the 'Beveridge curve.' It is so named following the work of William Beveridge (1944) who characterized it empirically in British data.

2.6 Firms' Optimization

Each firm i uses K_i and N_i, capital and labor, respectively, to produce output using $F(K_i, \xi N_i)$, a constant returns to scale production function. The parameter ξ is a labor-augmenting productivity parameter. The firm buys capital K_i at the price of its output and pays workers real wage w_i, derived below, which is taken as given by the firm. In the basic model there are no costs of adjustment for capital but adjusting labor involves linear costs; each vacancy costs the firm ξc and matches with a worker at the rate $q(\theta)$, where θ is outside the firm's control.

Each firm i is assumed to maximize expected discounted profits with respect to K_i and v_i:

$$\max_{K_i, v_i} \Pi_i = \int_0^\infty e^{-rt}[F(K_i, \xi N_i) - w_i N_i - \xi c v_i - \dot{K}_i - \delta K_i]dt, \tag{7}$$

subject to the evolution of employment, which conforms the matching and separation flows described above :

$$\dot{N}_i = q(\theta)v_i - \lambda N_i. \tag{8}$$

where r is the discount rate, and δ is the rate of depreciation of the capital stock.

Denoting by Ψ the co-state variable associated with this constraint, the following Euler conditions are obtained:

$$e^{-rt}[F_1(K_i, \xi N_i) - \delta] - \frac{d}{dt}(-e^{-rt}) = 0, \tag{9}$$

$$e^{-rt}[\xi F_2(K_i, \xi N_i) - w_i] - \lambda\Psi + \frac{d\Psi}{dt} = 0, \tag{10}$$

$$-e^{-rt}\xi c + q(\theta)\Psi = 0. \tag{11}$$

As $F(K_i, \xi N_i)$ is constant returns to scale, one can re-write $F_1(K_i, \xi N_i)$ and $F_2(K_i, \xi N_i)$ as functions of one variable, $K_i/\xi N_i$ to be denoted k_i. Define:

$$f(k_i) \equiv \frac{1}{\xi N_i} F(K_i, \xi N_i) \equiv F\left(\frac{K_i}{\xi N_i}, 1\right), \tag{12}$$

where $\xi f(k_i)$ is output per person employed. The relevant derivatives can be re-written as follows:

$$F_1(K_i, \xi N_i) = f'(k_i) \tag{13}$$

$$F_2(K_i, \xi N_i) = f(k_i) - k_i f'(k_i) \tag{14}$$

In the steady state ξ, r, Ψ and θ are constant. Hence equation (9) becomes:

$$f'(k_i) = r + \delta \tag{15}$$

which is the familiar condition for the optimal capital stock, and so the marginal product of labor is given by:

$$\begin{aligned} \xi F_2(K_i, \xi N_i) &= \xi \left[f(k_i) - k_i f'(k_i) \right] \\ &= \xi \left[f(k_i) - (r+\delta) k_i \right] \end{aligned} \tag{16}$$

Combining (10), (11), and (16) in the steady state yields:

$$\xi \left[f(k_i) - (r+\delta) k_i \right] - w_i = \frac{(r+\lambda)\xi c}{q(\theta)} \tag{17}$$

The RHS is positive and so the marginal product does not equal the wage. It is bigger than the wage in order to compensate the firm for the costs of vacancies.

One can define the value of a filled vacancy or of a job – to be denoted J – as these costs (ξc) times the average life of the vacancy (given by $\frac{1}{q(\theta)}$):

$$J \equiv \xi c \frac{1}{q(\theta)} \tag{18}$$

This allows for the re-writing of (17) as follows:

$$r(J_i + \xi k_i) = \xi \left[f(k_i) - \delta k_i \right] - w_i - \lambda J_i$$

Assuming free entry, all profit opportunities are used, driving the present value of a vacancy, to be denoted V, to zero, i.e., $V = 0$. Note that the flow value of a vacancy can be written:

$$rV_i = -\xi c + q(\theta)(J_i - V_i) \tag{19}$$

as the vacancy incurs costs ξc while open and with probability $q(\theta)$ becomes a filled job. Inserting $V = 0$ in this equation one gets equation (18) again.

I shall use these formulations below when deriving the wage solution.

2.7 Workers' Optimization

The worker earns w_i when employed and searches for a job when unemployed at intensity s_i. Search is costly and so a convex search cost function is assumed $\sigma_i = \sigma(s_i...)$, where the first two derivatives with respect to s_i are positive and there may be other factors affecting search costs. During unemployment the worker gets z, which represents unemployment insurance, imputed value of leisure, or income from work in the informal sector. The basic model assumes that z is constant and independent of market wages. The worker optimization problem is formulated as follows: worker i chooses search intensity s_i, facing the job finding probability given by

$$p_i = \frac{s_i}{s}\frac{m(su, v)}{u} \tag{20}$$

The worker maximizes the present value of earnings:

$$U_i = \frac{z - \sigma(s_i...) + p(s_i, s, u, v)(W_i - U_i)}{r} \tag{21}$$

where the asset value functions, U_i and W_i, denote the present discounted value of the expected income stream of, respectively, an unemployed and an employed worker. This can also be written in terms of a 'reservation wage' as follows:

$$rU_i = z - \sigma(s_i...) + p(s_i, s, u, v)(W_i - U_i) \tag{22}$$

Hence optimal search intensity is given by:

$$\sigma_s(s_i, ...) = \frac{\partial p_i}{\partial s_i}(W_i - U_i) \tag{23}$$

where σ_s is the derivative of σ with respect to s.

Employed workers earn a wage w_i and lose their jobs and become unemployed at the rate λ. Hence the present value of employment, W_i, satisfies

$$rW_i = w_i + \lambda(U_i - W_i). \tag{24}$$

The term rW_i is the permanent income of employed workers, incorporating the risk of unemployment. The basic model has no on-the-job search, so workers stay in their jobs as long as $W_i \geq U_i$. The necessary and sufficient condition for this to hold is $w_i \geq z$, for which a sufficient condition is $\xi \geq z$, which is assumed.

As all workers are the same they choose the same search intensity so $s_i = s$ and so using the latter with (20),(22),(23), and (24) the following is derived:

$$\sigma_s(s, ...) = \frac{w - z + \sigma_s(s, ...)}{r + \lambda + p} \frac{p}{s}$$

Search intensity depends on wages, unemployment income, the probabilities of job finding and separation, the interest rate, and any other variable affecting search costs.

2.8 Wage Bargaining

In this set up of search costs, a job match yields some pure economic rent, which is equal to the sum of the expected search costs of the firm and the worker (including foregone wages and profits). Wages need to share this economic rent, in addition to compensating each side for its costs from forming the match. The standard model assumes that this rent is shared according to the Nash (1950) solution to a bargaining problem. Bargaining takes place after the firm and the worker meet. Because all jobs are equally productive and all workers have the same unemployment value, the wage fixed for each job is the same throughout the economy. I shall therefore drop the index i. Note that each individual firm and worker are too small to influence the market, so when they meet they take the rest of the market as given. The wage contract is renegotiated whenever new information arrives, i.e., the wage continually satisfies the Nash sharing rule for the duration of the job.

The Nash bargaining solution is the w that satisfies (using W, U, J, and V as defined above):

$$w = \arg\max(W - U)^{\beta}(J - V)^{1-\beta}, \tag{25}$$

where $0 \leq \beta \leq 1$ represents worker bargaining power. For the interpretation of this parameter, see Binmore et al (1986).

The first-order maximization condition derived from (25) is:

$$W - U = \beta(J + W - V - U). \tag{26}$$

Using (18), (22) and (24), and the free entry condition $V = 0$, in equation (26), the wage is then given by:

$$\begin{aligned} w &= z + \beta\left[\xi\left(f(k) - (r+\delta)k + c\theta\right]\right) - z] \\ &= (1-\beta)z + \beta\xi[f(k) - (r+\delta)k + c\theta] \end{aligned} \tag{27}$$

The wage is equal to unemployment income (z) plus an expression that gives the worker a fraction β (the bargaining power) of the surplus. The latter consists of current productivity $\xi[f(k) - (r+\delta)k]$ and average hiring costs $\xi c\theta = \frac{\xi cv}{u}$, related to the match future productivity (via the firm optimization conditions) less unemployment income z. Alternatively, one can view the wage as a weighted average of unemployment income and current and future match productivity, with weights $1 - \beta$ and β, respectively.

2.9 Steady State Equilibrium

In what follows I present the equilibrium in steady state, distinguishing between the cases of exogenous and endogenous separations.

2.9.1 Exogenous Separations

Using equations (9)-(11) and for constant ξ and θ, there is a steady-state solution with constant w, N_i and K_i satisfying

$$F_1(K_i, \xi N_i) = \delta + r \tag{28}$$

$$\xi F_2(K_i, \xi N_i) = w + \frac{r+\lambda}{q(\theta)}\xi c \tag{29}$$

The steady-state solution for the firm's vacancies, v_i, is then obtained from the constraint (8) for $\dot{N}_i = 0$:

$$v_i = \frac{\lambda N_i}{q(\theta)}. \tag{30}$$

Substituting from (14) into (29) gives the job creation condition:

$$\xi c = q(\theta)\left[\frac{\xi[f(k_i) - k_i f'(k_i)] - w}{r+\lambda}\right] \tag{31}$$

With the firm homogeneity assumption, condition (31) implies that all firms choose the same k_i and so the subscript will be dropped.

We thus have a four equation system as follows (see (6), (27), (28) and (31)):

$$f'(k) = r + \delta \tag{32}$$

$$\xi c = q(\theta)\left[\frac{\xi[f(k) - kf'(k)] - w}{r+\lambda}\right] \tag{33}$$

$$w = (1-\beta)z + \beta\xi[f(k) - (r+\delta)k + c\theta] \tag{34}$$

$$u = \frac{\lambda}{\lambda + \theta q(\theta)} \tag{35}$$

The four equations are solved for the capital to effective labor ratio (k), market tightness (θ), the wage (w), and the rate of unemployment (u) for given values of the interest rate (r), the depreciation rate (δ), unemployment income (z) and the parameters ξ (productivity), c (vacancy costs), λ (separation), and β (worker bargaining power).

2.9.2 Endogenous Separations

The job destruction decision may be endogenized by considering a more general structure for the idiosyncratic productivity shocks. The basic idea is that at some of the idiosyncratic productivities production is profitable but at some others it is not. The firm chooses a reservation productivity and destroys jobs which productivity falls below it. When job destruction takes place, the firm and worker separate. This generates an endogenous flow of workers into unemployment.

The setup now includes the following elements, denoting by ξx the productivity of the job, where ξ denotes, as before, a general productivity parameter, and x an idiosyncratic one:

(i) When an idiosyncratic shock arrives, the productivity of the job moves from its initial value x to some new value x', which is a drawing from a general distribution $G(x)$ with support in the range $0 \leq x \leq 1$. Note that the model of the preceding sub-section can be reinterpreted as one that allowed only two values for the idiosyncratic parameter, 1 and 0.

(ii) Idiosyncratic shocks arrive to jobs at Poisson rate λ.

(iii) The idiosyncratic productivity that is drawn after the arrival of the shock is independent of initial productivity and is irreversible.

(iv) The firm has the choice either to continue production at the new productivity or close the job down and separate from the worker.

(v) At job creation, the firm has complete choice of job productivity. Profit maximization requires that all new jobs are created at maximum productivity, $x = 1$.

Mortensen and Pissarides (1994, 1999a) show that this set up generates the following key elements:

Reservation productivity. The optimal decision is that production should continue if $J(x) \geq 0$ but stop if $J(x) < 0$. $J(x)$ is a continuous function of x, so the job destruction rule $J(x) < 0$ satisfies the reservation property with respect to the reservation productivity R :

$$J(R) = 0. \tag{36}$$

Unemployment Dynamics. The dynamics of unemployment are driven by the flow into unemployment less the flow out of it. The former is equal to the fraction of jobs that get hit by a productivity shock below the reservation value; in a large market this is given by the product of the fraction of firms that get hit by a shock, λ, and the probability that the shock is below reservation, $G(R)$. The flow into unemployment is therefore given by $\lambda G(R)(1-u)$. As before, the flow out of unemployment is equal to matching of unemployed to vacancies i.e., $m(v,u) = \theta q(\theta)u$. The dynamics of unemployment are therefore given by:

$$\dot{u} = \lambda G(R)(1-u) - p(\theta)u \tag{37}$$

and steady-state unemployment is:

$$u = \frac{\lambda G(R)}{\lambda G(R) + p(\theta)}. \tag{38}$$

Wage Bargaining. Wages are still set through Nash bargaining so as before:[3]

$$w(x) = (1-\beta)z + \beta\xi(x + c\theta). \tag{39}$$

Job Creation Job creation is given by:

$$(1-\beta)\frac{1-R}{r+\lambda} = \frac{c}{q(\theta)}. \tag{40}$$

Equation (40) says that the expected gain from a new job to the firm (the LHS) must be equal to the expected hiring cost that the firm has to pay (the RHS). General productivity ξ does not enter this expression because both the firm's expected revenues and costs are proportional to ξ.[4]

Job Destruction. The job destruction condition is given by:

$$R = \frac{z}{\xi} + \frac{\beta c}{1-\beta}\theta - \frac{\lambda}{r+\lambda}\int_R^1 (s-R)dG(s). \tag{41}$$

Reservation productivity, R, is less than the reservation wage of unemployed workers, rU.[5] The reason for this is that occupied jobs have a positive 'option value', which implies that there

[3] Where in the notation of (27) productivity x is $f(k) - (r+\delta)k$.

[4] Note that $R \leq x \leq 1$ as firms will close down jobs with $x < R$ hence the $1-R$ expression.

[5] This is given by:

$$rU = z + \frac{\beta}{1-\beta}\xi c\theta.$$

is some labor hoarding. This option value is shown by the integral expression in (41). Because of the possibility that a job productivity might change, the firm keeps some currently unprofitable jobs occupied. By doing so it is able to start production at the new productivity immediately after arrival, without having to pay a recruitment cost and forego production during search.

Equilibrium Solution. The four equations – 38, 39, 40 and 41 – are used to uniquely solve for the four unknowns in the steady state: unemployment u, the reservation productivity R, wages w, and market tightness θ, for given values of the variables r, δ, z, the productivity distribution $G(x)$, and the parameters ξ, c, λ, and β. This may be done by deriving the wage equation at all productivities, use it to substitute wages out of the job creation and job destruction conditions and then use the latter two conditions to solve for R and θ. With knowledge of R and θ, unemployment can then be obtained from the Beveridge curve, equation (38).

2.10 Closing the Model in General Equilibrium

The interest rate r is exogenous in the afore-going model. Embedding this model in a GE framework makes it endogenous, and labor market variables are endogenously derived together with other macroeconomic variables, like consumption and investment. Such a framework is proposed by Merz (1995) and Andolfatto (1996), which essentially embed the model in a RBC framework. A key assumption that enables this modelling approach is that each household is perceived as a large extended family which contains a continuum of members. Members is each family perfectly insure each other against variations in labor income due to employment and unemployment. This enables the modelling of risk averse households and tackles the problem whereby households are identical but not all of their members are employed. The empirical performance of this model is discussed below.

An alternative approach is discussed by Pissarides (2000, Chapter 3.4), where capital market equilibrium derives from a Solow growth model. Savings are a fraction s of output and constitute the supply; a user cost condition generates the demand. The rate of interest and the capital stock are then determined in equilibrium.

2.11 Efficiency

Hosios (1990) looks at the standard model, and building on the insights of Diamond (1982 a,b), Mortensen (1982 a,b), and Pissarides (1984) on the externalities inherent in the model, derives a set of conditions for constrained Pareto efficient resource allocation. The externalities involved are entry/exit externalities, job acceptance externalities, and search/recruiting externalities. The entry/exit externalities relate to the congestion and trading effects: an additional worker (firm) makes it easier (harder) for vacancies to find workers but harder (easier) for workers to find jobs. The job acceptance externalities relate to the fact that workers and firms stop searching, i.e., exit, when accepting a match and this changes the job matching probabilities of existing searchers in ways ignored by exiting agents. The search/recruiting externalities refer to search and recruitment expenditures that are generally inefficient, as optimal expenditure decisions ignore the share to be obtained by future trading partners. The key result is that in the basic model with a CRS matching function, the relevant efficiency condition pertains to the sharing of the match surplus and to the matching function. This condition, which internalize the externalities, is:

$$\beta = \frac{um_u}{m} \tag{42}$$

i.e., that the worker bargaining power parameter equal the elasticity of the matching function with respect to unemployment. In other words, this is the equality of the worker share of the surplus and the worker's contribution to matching. When the worker gets in wages his/her social contribution the equilibrium is efficient. Some models, such as the RBC models discussed above, assume a-priori that this condition holds true.

2.12 The Development of the Literature

The antecedents to the development of the basic ideas of the model were made in the Phelps (1967) and Friedman (1968) critique of the Phillips curve and the proposition of the 'natural rate' idea and in the papers by Phelps (1970), Holt (1970) and, in particular, Mortensen (1970). The last three papers, appearing in the celebrated 1970 'Phelps volume,' introduced the flow approach to the labor market, search costs, and the idea that the firm's intertemporal choice is akin to investment with adjustment costs.

The key papers that have contributed the main building blocks of the model, as described above, are Diamond (1982 a,b), Mortensen (1982 a,b,) and Pissarides (1979, 1985).

More specifically, the key elements of the model were developed as follows:

Matching and Wage Determination. A key element of the model is the formulation of the matching of workers and firms and the determination of wages. As the following short description implies, after some experimentation with other modelling routes, the literature settled on the concept of random matching, captured by a matching function, and the Nash bargaining solution for division of the match surplus.

Mortensen (1978) presented a framework for analyzing the interrelationship between the choice of search strategies by the two parties involved in an existing match and the nature of the wage bargaining problem. The problem of searching for a preferred partner was formulated as two-person game played by the worker and the employer involved in the existing match. The paper compares the non-cooperative Nash solution of the game to the joint wealth maximizing search strategies. The main findings are that quit and dismissal rates are higher in the former relative to the latter, in the absence of a provision for compensation. These turnover rates depend on wages in the non-cooperative case, but are independent of wages in the joint wealth maximizing case.

Diamond and Maskin (1979) studied the steady-state equilibrium of models where individuals meet pairwise in a costly stochastic search process and negotiate contracts to product output. Different meetings yield different outputs, and so an individual in a contract may wish to continue search to find a better match and break his or her original contract. Individuals' search decision may cause externalities. In anticipation of possible breaches, contracts may provide for compensation to be paid to the breached-against partner. The paper examines the effects that several alternative damage rules have on equilibrium search and breach behavior.

Pissarides (1979) formalized a model of matching with two alternative methods of search: random search and registration at a centralized employment agency. He introduced the concept of the matching function in the context of market equilibrium.[6]

Mortensen (1982a,b) dealt with the following issue: two types of agents search for each other in order to exploit a joint production opportunity. The way the value of the match is divided affects the incentives of the agents when searching for the match. An equal division of the surplus was shown by Mortensen (1982a) to yield too little effort by both types of agents. Mortensen (1982b) showed that search effort made by all agents in a Nash equilibrium is efficient when the matchmaker receives all the surplus.

Diamond (1982a) analyzed a model with trade coordinated by a stochastic matching process. He emphasized the externalities involved and showed that there are multiple steady state rational expectations equilibria and that there is no unique natural unemployment rate. Diamond (1982b) derived the steady state equilibrium negotiated wage as a function of equilibrium unemployment and vacancy rates, using the Nash bargaining solution. This latter formulation is the one that has become standard, as presented above in Section 2.8.

Free entry. The application of zero-profit conditions for new jobs, closing the model with endogenous demand for labor, as discussed in Section 2.6 above, was proposed by Pissarides (1979, 1984).

Externalities and Efficiency. Mortensen (1982a,b), Diamond (1982 a,b), and Pissarides (1984) analyzed efficiency aspects of the above matching and bargaining situations, emphasizing the search and congestion externalities involved, and the potential role of policy. The conditions

[6] Petrongolo and Pissarides (2001) offer a comprehensive survey of the literature on the matching function.

for efficiency were subsequently formally derived by Hosios (1990), as discussed in Section 2.11 above.

Out of steady state dynamics. Pissarides (1985,1987) provided a detailed characterization of the dynamics of the model out of steady state and the convergent path. The model in Pissarides (1987) generates cycles in unemployment in response to temporary shocks to output while unemployment does not change when shocks are permanent, a distinction that was previously absent from the literature. I refer to this analysis below.

Endogenous Separations. Mortensen and Pissarides (1994) extended the model to incorporate idiosyncratic productivity and endogenous separations, as presented in Section 2.9.2 above.

3 Going Deeper: Model Extensions

In this section I discuss extensions of the basic model. Each aspect of the model is studied in greater depth, yielding either an extension that fits in with the basic model, or an alternative formulation to at least one of its components.

3.1 Generalization of the Firm's Hiring Costs

The basic model assumes linear adjustment costs of labor only. This is modeled as a linear function of vacancies, cv. More general formulations allow for: (i) convexity of costs; (ii) adjustment costs for capital; (iii) interaction between adjustment costs for capital and those for labor.

Point (i) was shown to be empirically relevant in structural estimates reported by Yashiv (2000a,b). His formulation is given by:

$$\Gamma_t = \left[\frac{\Theta}{1+\gamma} \left(\frac{\phi v_t + (1-\phi) q_t v_t}{n_t} \right)^{\gamma+1} \right] f_t \qquad (43)$$

where costs are proportional to output f. Given in terms of rates out of employment n, in order to take into account the scale of the firm, the expression in square brackets has the interpretation of a percentage of output lost on adjustment costs. The cost function has a degree of convexity

$\gamma + 1$, and its arguments are a weighted average (with weight ϕ) of vacancies and hiring. This formulation allows for separate cost formulations for posting, advertising and screening (a function of total vacancies, v) and for training (a function of actual hires, qv). Moreover, Yashiv (2006a) shows that such a convex formulation is needed to make the model fit U.S. business cycle facts. This is so because convex adjustment costs, relative to linear ones, generate two features: they make hiring more sluggish and hence serve to increase the persistence of key variables, and they make for a negatively sloped Beveridge curve.[7] Both features correspond to the data.

Point (ii) was examined by Den Haan, Ramey, and Watson (2000). Capital adjustment costs are added to the model in the form of imperfections in negotiating capital rental contracts, motivated by the idea that renting capital to a firm involves a certain amount of commitment by the capital supplier. They show that interactions between capital adjustment and the job-destruction rate, linked to reductions in capital demand and household investment, play an important role in propagating shocks. The mechanism is as follows: a negative productivity shock generates a spike in job destruction, and employment remains persistently lower on account of matching frictions. Lower employment reduces the demand for capital, leading to a lower supply of capital in future

[7] The reason for the latter is somewhat involved. Marginal costs (MC) and the the matching rate (q) are given by:

$$
\begin{aligned}
MC &= \Theta\,(\phi + (1-\phi)q)\,(\frac{\phi v + (1-\phi)qv}{n})^{\gamma}\frac{f}{n} \\
q &= \frac{v}{u}^{-\sigma}
\end{aligned}
$$

where γ is the degree of convexity of marginal costs, Θ is a scale parameter, and σ is the elasticity of the matching function. The relevant F.O.C is:

$$
\Theta\,(\phi + (1-\phi)q)\,(\frac{\phi v + (1-\phi)qv}{n})^{\gamma} = q * \pi
$$

with π being marginal profits as a fraction of $\frac{f}{n}$. Suppose $\gamma = 0$ as in the linear case. Hence $\Theta\,(\phi + (1-\phi)q) = q\pi$ and, other things equal, as u rises, v needs to rise to keep q constant. This implies a positive $v - u$ relationship, counterfactually. With a convex function $\gamma > 0$. In this case v also responds to $n = 1 - u$, and there can exist a negative $v - u$ relationship.

periods. The productivity shock thereby reduces the equilibrium capital stock, magnifying the future output effects of the shock. To verify that interactions between capital adjustment and job destruction play a central role, the authors show that propagation effects are much reduced if either capital-stock adjustments or fluctuations in the job-destruction rate are suppressed. They also show that propagation effects are significantly greater when the model is extended to introduce costs of adjusting capital across firms.

Points (i), (ii) and (iii) jointly were explored for the U.S. economy by Merz and Yashiv (2005). They use a function similar to (43) but add adjustment costs for capital investment and an interaction term between hiring costs and investment costs. Calibrating and simulating the model for the U.S. economy, they show that this formulation enables the model to jointly explain investment and hiring behavior. The interaction term is shown to be particularly important for fitting the data. The estimates of the coefficient of this interaction term are found to be negative, implying the optimality of simultaneous hiring and investment. One interpretation of this result is that simultaneous hiring and investment is less costly than sequential hiring and investment of the same magnitude. This may be due to the fact that simultaneous action by the firm is possibly less disruptive to production than sequential action. The authors stress the following distinction: the afore-going argument favors simultaneous hiring and investment, i.e., positive levels of both $(\frac{i}{k}, \frac{qv}{n} > 0)$. But it does not necessarily imply positive co-movement or correlation between hiring and investment rates (i.e., $\rho(\frac{i}{k}, \frac{qv}{n}) \lesseqgtr 0$). In other words investment and hiring take place at the same time, but it is possible to have one rise while the other declines.

3.2 On the Job Search

The basic model does not allow for on the job search because all workers and jobs are assumed homogenous. This assumption has been relaxed in various ways.

Pissarides (1994) allows for on the job search in the standard model. This is enabled by postulating 'good' and 'bad' jobs, the former being more productive but also more costly to create. Output depends on job-specific human capital, which is accumulated over time. Only the unemployed are prepared to fill vacancies of bad jobs. Workers in bad jobs search for better ones, up to a time limit, set optimally; the limit is due to the fact that workers accumulate sufficient human capital so as to render a move to a better job less profitable. The key decision for firms is how many jobs of each type to bring into the market. In this set up, a positive productivity shock induces more employed workers to search, creating congestion for other workers, and generating a shift of the job composition into more good jobs, as the latter have a higher flow of applicants. It becomes harder for the unemployed to find work, due to the congestion and the changing job mix. Hence the decline in unemployment following a positive shock slows down; job vacancies become more volatile.

Krause and Lubik (2004) develop a dynamic general equilibrium model along similar lines. The model predicts fluctuations of unemployment, vacancies, and labor productivity, which relative magnitudes replicate the data. They propose the following mechanism: in a boom, rising search activity by employed workers expands the pool of potential hires for firms, in addition to those searching from unemployment. As a consequence, the bargaining power of incumbent and newly hired workers rises by much less than would be suggested by the standard vacancy-unemployment ratio. As a result, wages are endogenously rigid in the presence of on-the-job search. Two features of the model are key: the endogeneity of on-the-job search and the heterogeneity of jobs. The former amplifies the incentives to create good jobs in a boom, since the likelihood of filling a vacancy remains large, in spite of falling unemployment. The latter, that is, the increasing availability of good vacancies, raises employed workers' search effort. Without either element, the response of job-to-job transitions and the propagation of shocks on output would be much weaker. This complementarity explains the prolonged effect of shocks. Furthermore, not only are more new jobs created, but the job composition shifts towards more productive jobs, which raises aggregate output.

Nagypal (2005) considers ex-ante identical firms and workers but assumes the existence of a distribution of idiosyncratic job values for the worker. Workers can search for a job with higher value, at a cost, both while unemployed and while employed. Unemployed workers are "desperate", as they are willing to accept any idiosyncratic value above some minimum threshold. Employed workers are more selective, and only accept matches that have a value above that of their current match. Turnover, in turn, declines with the idiosyncratic value of the match for two reasons. First, the probability of finding a better match declines, and second, as a consequence, the incentives to search for a better job also decline, thereby leading to lower endogenous search effort. This then means that the expected turnover of previously unemployed workers is higher than that of previously employed workers, making them less attractive candidates for firms to hire. This higher turnover has to be weighed against the higher acceptance rate of unemployed workers. It is shown that the turnover effect can outweigh the acceptance rate effect only if there is a possibility of firms making negative profits in a match, which naturally arises when the firm has no information about the idiosyncratic value of the match to the worker and has to bear one-time match-specific costs to start the relationship.

There is a class of models whereby both firms and workers search while matched. A recent contribution to this class of models, which also offers a discussion of previous contributions, is Kiyotaki and Lagos (2005). The model features a continuum of fixed and equal numbers of workers and employers, who are ex-ante homogeneous in tastes and technology. The workers and firms randomly meet according to a Poisson process. Upon meeting, the employer-worker pair randomly draws a production opportunity of productivity, which represents the flow net output each agent will produce while matched. A key element is that matched and unmatched agents meet potential partners at the same rate, so when an employer and a worker meet and draw a productive opportunity each of them may or may not already be matched with an old production partner, but each worker and employer can form at most one productive partnership simultaneously. When a worker and an employer meet and find a new productive opportunity, the pair and their old partners, if they have any, determine whether or not the new match is formed, as well as the once-and-for all side payments that each party pays or receives, through a bargaining protocol. Utility is assumed to be transferable among all the agents involved in a meeting. The paper proposes a notion of competitive equilibrium based on the particular bargaining procedure used and explores its efficiency properties. A key innovation, relative to older models, is the feature of the model whereby it has a flexible bargaining process involving side payments, without requiring that agents be able to commit to compensate their partners in case of future breaches of contract. The resulting model has many of the stylized properties of actual labor markets: worker flows exceed job flows, displaced agents suffer persistent reductions in permanent incomes, job-to-job transitions are common, and firms often engage in simultaneous hiring and firing.

On the job search also arises in models of learning such as those of Jovanovic (1979 a,b) and the islands model of Lucas and Prescott (1974), discussed below.

In micro-based models, mostly those with wage posting, on the job search is a key feature. These models are beyond the scope of the current survey (see the brief discussion in Section 7 below).

3.3 The Matching Process

Attempts are being made to go into the "black box" of the matching process. In what follows I outline some key models.

Early formulations used an urn-ball structure, where workers (balls) are randomly assigned to jobs (urns); Butters (1977) introduced the essential idea (see Hall (1977) for the use in the unemployment context). The random assignment ensures that some jobs are unfilled (yielding vacancies), and some jobs are assigned multiple workers, only one of whom can be hired (yielding unemployment).

A more recent development is the concept of stock-flow matching; Coles and Smith (1998) is a prominent paper in this developing literature. The formulation in Section 2 assumed random search, implying that matched agents are randomly selected from the pool of existing unemployed workers and job vacancies, independently of the duration of search on either side of the match. The stock-flow model emphasizes the systematic elements in search, i.e., non-random matching.

In this approach, the role of information is recognized. With the use of information, job seekers have complete information about the location of available vacancies and apply simultaneously to as many they like. Upon contact, the firm and the worker decide whether to form a match and start producing or go back to search. Those who remain unmatched and keep searching do so because there are no trading partners that are suitable for them among the existing pool. An important implication is that no job vacancy or unemployed worker who has been through one round of sampling will attempt to match later with a pre-existing job seeker or vacancy.[8]

Lagos (2000) derives a matching function with microfoundations. The main difference with the previous modelling is that meeting frictions are not assumed but, rather, are shown to arise endogenously. Agents direct their search and no information imperfections are assumed. The model's spatial structure and the agents' moving decisions are spelled out, so that the number of contacts that occur depends on the way agents choose to locate themselves. The example used is a dynamic market for taxicab rides in which taxicabs seek potential passengers on a grid. All taxicabs do is try to position themselves in a location in which they can contact a passenger. This is a market in which meeting frictions are quite visible: vacant taxicabs spend long periods of time waiting for passengers in some parts of the city while at the same time, passengers often

[8] To express this formally, denote matches by M, the stock of unemployment by U, the inflow of unemployed workers by $\overrightarrow{u}$, and the job finding rate by κ. The probability of remaining unemployed is given by $e^{-\kappa t}$ and thus the probability of being matched is the complement $1 - e^{-\kappa t}$. Assuming constant $\overrightarrow{u}$ and κ, the resulting matching function is given by the following unemployment outflow equation:

$$\begin{aligned} M &= (1 - e^{-\kappa})U + \int_0^1 [1 - (1 - e^{-\kappa(1-t)})]\overrightarrow{u_t} dt \\ &= (1 - e^{-\kappa})U + [1 - \frac{1}{\kappa}(1 - e^{-\kappa})]\overrightarrow{u} \end{aligned}$$

The first term on the RHS describes the workers in the existing unemployment stock who match with the new vacancies flow. The second expression is the matching of the inflow of new unemployed workers matching with the existing stock of vacancies. A symmetric expression can be derived for the vacancy outflow, with the relevant matching rate. A possible variation is to allow for a fraction of the newly unemployed workers to match immediately.

wait for taxicabs in other locations. What is necessary is some heterogeneity among locations, so that the equilibrium will exhibit frictions. The latter depend crucially on the total numbers of searchers on each side of the market as well as on the heterogeneity among locations. Lagos shows that a function that expresses the total number of meetings in terms of the aggregate stocks of searchers on both sides of the market exists, and he studies its behavior with respect to changes in parameters, such as distances between locations, the agents' payoffs, and the sizes of the populations of searchers. Since agents can direct their search, changes in parameters affect search strategies, altering the shape of the matching function. This suggests an interesting policy implication: the results of policy experiments based on models that assume an exogenous meeting process are likely to be misleading if the random search assumption is not a good characterization of the agents' underlying search behavior. Rather, if agents are able to direct their search, then the matching function is an equilibrium object, sensitive to policy.

Two recent papers depart from the standard matching model to propose alternative concepts within a search framework:

Sattinger (2005) applies methods of queueing theory to the analysis of a labor market with frictions. Queueing in a labor market occurs when a worker can get a job by waiting at a firm for a position to become available. Allowing queues benefits firms because labor queues reduce firm vacancies. Unemployed workers can benefit from choosing to queue by reducing the expected time until employment. Unemployed workers search among firms either for a vacancy or for a queue that is not too long. With fairly straightforward assumptions, it is possible to obtain analytical expressions for the expected numbers of firm vacancies, searching workers, and queueing workers for a given aggregate ratio of workers to firms. The results generate a Beveridge curve without the assumption of a matching function. Queueing theory also carries implications for the dynamic adjustment of labor markets with frictions. Changes in unemployment take place mostly through the number of workers in queues rather than through the number of workers actively searching. In a comparison with the standard search and matching model, queueing places limits on the numbers of unemployed workers who are searching. As a result, at higher ratios of workers per firm, the arrival rate is lower when there is queueing.

Shimer (2005c) develops a dynamic model of mismatch. Workers and jobs are randomly assigned to labor markets. Each labor market clears at each instant but some labor markets have more workers than jobs, hence unemployment, and some have more jobs than workers, hence vacancies. As workers and jobs move between labor markets, some unemployed workers find vacant jobs and some employed workers lose or leave their job and become unemployed. The model is shown to be quantitatively consistent with the co-movement of unemployment, job vacancies, and the job finding rate of unemployed workers over the business cycle in U.S. data.

3.4 Heterogeneity

There are a number of attempts to use the search and matching framework with heterogenous agents. A key contribution is Mortensen and Pissarides (1994), which is the model with idiosyncratic productivity shocks and endogenous separation rates presented above in Section 2 (see 2.9.2 in particular). Another strand of models relates to on the job search, as discussed above. The basic motivation for this endeavor is evidently realism, as we are increasingly aware of the role played by heterogeneity (workers' skills and preferences, firms' productivities and skill requirements) even for aggregate, macro variables. The phenomena of skill-biased technological change and increasing trade and immigration make these issues even more pertinent. More specifically, there has been much effort in trying to account for increasing wage inequality in the U.S. and other countries and for differences in labor market outcomes (unemployment, wages, employment growth) between the U.S. and continental European countries.

Acemoglu (1999) presents a model where firms decide what types of jobs to create and then search for suitable workers. When there are few skilled workers and the skilled-unskilled productivity gap is small, firms create a single type of job and recruit all workers. In response to changes in the skill level of the labor force or technology, jobs open both to skilled and unskilled workers may be replaced by high-quality (capital) jobs designed for the skilled and low-wage jobs targeted at the unskilled. This change in the composition of jobs leads to higher skilled wages, lower unskilled wages, and higher unemployment rates for both skilled and unskilled workers. The model relies on two crucial ingredients: the first is the presence of search frictions, which makes it costly for firms to find suitable workers, and a long time for workers to find suitable jobs. The second ingredient is that firms have to choose what type of job to open before meeting a worker. These two ingredients imply that the skill composition of the labor force affects the types of jobs that firms want to create. For example, when the supply of skills is limited, it is not profitable to create jobs specially designed for the skilled, because it is difficult to find skilled workers and these jobs would not be as productive when employing unskilled workers.

Moscarini (2001) develops an equilibrium search-frictional Roy model, which features a continuum of skills and a finite number of job types. The model posits that workers choose types of jobs based on a trade-off between microeconomic incentives, captured by their individual comparative advantage (such as formal education), and macroeconomic incentives (such as unemployment). When unemployment is low and the labor market is tight, workers can afford to wait for the "perfect" job, and comparative advantages matter. Labor mobility across occupations is lower and matching is more successful. In a weak labor market there will be excess worker reallocation due to the higher cost of waiting.

Albrecht and Vroman (2002) consider a labor market in which workers differ in their abilities and jobs differ in their skill requirements. The distribution of worker abilities is exogenous but the choice of skill requirements by firms is derived endogenously. High-skill jobs produce more output than low-skill jobs, but high-skill jobs require high-skill workers and thus are more difficult to fill. The model uses key ingredients from the standard model to determine the equilibrium mix of job types, along with the equilibrium relationship between worker and job characteristics, wages, and unemployment. Equilibrium is determined by two free-entry conditions, namely, that the values of maintaining low- and high-skill vacancies be zero, plus two steady-state conditions equalizing the flows of the two worker types into and out of unemployment. Depending upon the underlying parameter configuration, it can take one of two forms. The first type of equilibrium is one in which matches between high-skill workers and low-skill vacancies are mutually beneficial and therefore consummated. In the second type of equilibrium, these potential matches do not form; that is, high-skill workers only take high-skill jobs. The model generates equilibria with several realistic features: first, wage dispersion both within and across skill groups – high-skill workers are paid more on average than low-skill workers and, at the same time, when they match with both types of jobs, they earn more in high-skill jobs than do identical high-skill workers employed in low-skill jobs. Second, differences in unemployment duration across skill groups – if high-skill workers take low-skill jobs, then unemployment duration among low-skill workers is higher on average than among the high-skill workers. If, on the other hand, high-skill workers do not work at low-skill jobs, then this pattern can be reversed. Third, expected vacancy durations are always longer for high-skill jobs than for low-skill jobs.

3.5 Matching and Learning

An influential approach to matching was developed by Jovanovic (1979a,b, 1984). This is a model where there is gradual learning of the quality of the match, with the match being a pure experience good. A worker's productivity in a particular job is not known ex-ante and becomes known more precisely as the worker's job tenure increases. There is a distribution of worker productivity across different jobs, hence job to job movements (turnover), and an equilibrium wage contract, whereby at each moment in time the worker is paid his marginal product, conditional on all available information at that time. Firms contract workers on an individual basis. Turnover is a phenomenon of optimal reassignment caused by the accumulation of better information with the passage of time. The model is designed to explain phenomena related to tenure and turnover, such as wages rising with tenure, and negative correlations of quits with tenure and with wages. When combined with a search model, where also unemployed workers receive job offers, it is able to generate endogenous moves both from job to job and into and out of employment.

Moscarini (2005) brings together the Jovanovic model, which is micro-based, and the

Mortensen and Pissarides (1994) model, which takes a macroeconomic equilibrium approach. This is a highly challenging endeavor and is ingeniously achieved by the following three modelling devices: (i) the unknown match quality may take only one of two values; this makes the micro model tractable for aggregation; (ii) wages are set by generalized Nash bargaining, which subsumes the competitive formulation of Jovanovic; (iii) an outside offer to an employed worker triggers a trilateral renegotiation problem, and so the two firms play an English auction to win the worker. There are two key results to this model. One is that the resulting equilibrium wage density exhibits the three main features of empirical wage distributions: a unique mode, skewness like a log-normal, and a long and fat right tail of Pareto functional form. The other is that the larger the idiosyncratic productivity uncertainty with respect to match quality, the higher the (Pareto) rate of decay of the upper tail of the wage distribution. The selection of good matches, through optimal quits to unemployment and to other jobs, redistributes mass of workers from the lower to the upper part of the distribution of beliefs about match quality, which determine wages. This explains the skewness and the fat Pareto tail, in spite of symmetric and Gaussian (thin-tailed) noise in output.

Pries and Rogerson (2005) combine variants of the Jovanovic learning model and the standard model. Job flows are driven by idiosyncratic shocks to job productivity, and worker turnover (in excess of job turnover) is driven by the stochastic accumulation of information about match quality. The Jovanovic model is modified by assuming that match quality is both an inspection good and an experience good. Both parties to a match observe a signal about the match's true quality prior to deciding whether to form a match, and matches form only if the signal about match quality exceeds a threshold value. True quality is revealed over time, but only if a match is formed. Labor market regulations affect worker turnover in the model by influencing hiring practices, that is, the level of the threshold signal. Worker turnover in excess of job turnover results from the desire to create high-quality matches. Hiring practices play an important role in the resource allocation process in this economy: firms and workers decide how much screening takes place prior to forming a match. The authors show analytically that equilibrium hiring practices are influenced by various labor market policies. These changes in hiring practices will influence observed labor market dynamics and in particular affect measures such as worker turnover and unemployment durations. The model is used to study labor market policy and I return to it in Section 6.3 below.

3.6 The Asset Value of the Match and the Asset Value of the Firm

Merz and Yashiv (2005) show that the model can be used to explain asset prices. They build on the production-based model for firms' market value proposed by Cochrane (1991) and insert frictional labor markets and capital adjustment costs as crucial ingredients. They qualitatively illustrate how firms' market value is linked to the flows of gross hiring and gross investment and to the stocks of employment and physical capital. This link results from the following mechanism: firms decide on the number of vacancies to post in order to hire workers and on the size of the investment in physical capital to undertake in their effort to maximize their market value. Doing so they face labor market frictions interacting with adjustment costs for capital. Optimal hiring and investment determines firms' profits – including rents from employment – and consequently their value, as well as the time path of employment and capital.

The authors then structurally estimate the model for the U.S. economy. The results show that with estimates of adjustment costs of moderate magnitude, one can characterize optimal hiring and investment. The implied present values of hiring and of investment account fairly well for the predicted component of firms' value, over and above the size of the physical capital stock.

3.7 Summing Up

What, then, is the state of the art? On the one hand, there is by now modelling that takes care of some of the fundamental deficiencies of the standard model. Thus, for instance, there is treatment of heterogeneity (jobs, workers, matches), endogenous separations, interactions with capital investment, learning, and on the job search leading to job to job movements, which were absent from the earlier models. On the other hand, there are some new difficulties: with heterogeneity and on the job search there is great analytical difficulty in implementing the Nash bargaining solution for wages. Different papers have taken different routes in modelling heterogeneity, the process of on the job search, and the derivation of wages. There is no one, accepted model, or one that has been shown to be empirically superior, and what has emerged looks like a loosely connected collection of advanced models. Going forward it seems that the ability to match the data may now play a bigger role in the formulation of a more comprehensive model. The earlier models laid down key principles. It is now the time to match the models with the data and strive for empirically valid formulations. I turn now to the examination of the empirical work done thus far.

4 The Empirical Evidence

The search and matching model aims to explain the behavior of traditional labor market variables, such as employment, unemployment, and wages. But beyond that, it is a model of labor market dynamics, and so labor market flows are key variables to be explained. In order to understand the relevant empirical issues it is useful to consider the dynamic equations of the labor market. These equations are discussed in 4.1. I then present the data on worker flows and their interpretation (4.2) and discuss their relationship with job flows (4.3). Next, I discuss estimation of the matching function (4.4). Finally I look at the estimation of the full model (4.5).

4.1 Labor Market Dynamics

The dynamic equations for the labor market recognize that in addition to the official pool of unemployed workers, there is another relevant pool of non-employed workers within the 'out of the labor force' category, and that there are substantial flows between the latter and employment.

The evolution of employment proceeds according to the dynamic equation

$$N_{t+1} = N_t + M_t^{UN+ON} - S_t^{NU+NO} \tag{44}$$

where N is the employment stock, M^{UN+ON} are gross hiring flows from both unemployment (U) and out of the labor force (O) and S^{NU+NO} are separation flows to these pools. In terms of rates this equation may be re-written as:

$$\frac{N_{t+1}}{N_t} - 1 = \frac{M_t^{UN+ON}}{N_t} - s_t^{NU+NO} \tag{45}$$

where $s = \frac{S}{N}$ is the separation rate.

A similar equation holds true for unemployment dynamics:

$$U_{t+1} = U_t(1 - p_t^{UN}) + s_t^{NU} N_t + F_t^{OU} \tag{46}$$

where U is the unemployment stock, p^{UN} is the hiring rate from unemployment, and F_t^{OU} is the net inflow of workers from out of the labor force, joining the unemployment pool.

This can be re-written:

$$\frac{U_{t+1}}{U_t} - 1 = -p_t^{UN} + s_t^{NU} \frac{N_t}{L_t} \frac{L_t}{U_t} + \frac{F_t^{OU}}{L_t} \frac{L_t}{U_t} \tag{47}$$

In steady state there is a constant growth rate of unemployment at the rate of labor force growth to be denoted g^L:

$$\frac{U_{t+1}}{U_t} - 1 = g^L \tag{48}$$

Thus the unemployment rate is constant at $\overline{u}$:

$$\overline{u} = \frac{U}{L} \tag{49}$$

The dynamic equation (47) becomes:

$$g^L = -p^{UN} + s^{NU}(1 - \overline{u}) \frac{1}{\overline{u}} + \frac{F^{OU}}{L} \frac{1}{\overline{u}} \tag{50}$$

Hence steady state unemployment is given by

$$\overline{u} = \frac{\frac{F^{OU}}{L} + s^{NU}}{p^{UN} + g^L + s^{NU}} \tag{51}$$

In case there is no growth or workers joining from out of the labor force, i.e., $\frac{F^{OU}}{L} = g^L = 0$, this becomes:

$$\overline{u} = \frac{s^{NU}}{s^{NU} + p^{UN}} \tag{52}$$

This is the same equation as (6).

Hence in order to explain employment and unemployment one needs to account for p and s. These variables, as discussed in Section 2, are the product of search by firms and workers and of matching. Noting that $M_t = p_t U_t$ and $s_t = \frac{S_t}{N_t}$, the empirical researcher needs data on the stocks U_t and N_t and on the flows M_t and S_t. I turn now to discuss these data and their interpretation.

4.2 Worker Flows

I present the sources of the data, list the major studies, and then discuss the interpretations of these data and some ensuing controversies.

4.2.1 Data Sources

Data on aggregate worker flows in the U.S. come from two main sources: the Current Population Survey (CPS) and the Job Openings and Labor Turnover Survey (JOLTS), both of the Bureau of Labor Statistics (BLS). The CPS is the basis for the analysis of gross worker flows by Blanchard and Diamond (1989, 1990), Ritter (1993), Bleakley, Ferris and Fuhrer (1999), Fallick and Fleischmann (2004), and Shimer (2005b). JOLTS data are reported and discussed by Hall (2005b); see also Davis (2005) for a critique of the latter. A summary of data sources and a discussion of them is to be found in Davis, Faberman and Haltiwanger (2005). For earlier overviews of data sources on worker flows in the U.S. see Farber (1999) and Davis and Haltiwanger (1998, 1999a).

For descriptions and analysis of gross flows in European countries see Pissarides (1986), Burda and Wyplosz (1994), Van Ours (1995), Contini and Revellii (1997), Albaek and Sorensen (1998), and Layard et al (2005).

The problems with treating these data and their methods of adjustment, including issues of matching individual responses, misclassification, aggregation across sectors and over time, survey methodology changes, and seasonal adjustment, are discussed in Abowd and Zellner (1985), Poterba and Summers (1986), and in the above papers.

4.2.2 Data Interpretation and Controversies

Pissarides (1986) examined worker flows and vacancy data to explain the evolution of unemployment in the U.K. He found that changes in unemployment in Britain have been driven mainly by changes in the rate at which unemployed workers move into employment. The rise in unemployment after 1974 was mainly the result of a fall in the demand for labour. Of the 12 percentage points rise in unemployment between 1974 and 1983, approximately eight points can be attributed to redundancy and to a fall in the number of job vacancies posted by firms.

Much of the relevant research, however, was focused on the U.S. economy. The studies cited above indicate that the average monthly matching rate from unemployment ($\frac{M^{UN}}{N}$) is around 1.5%-1.7%, and its standard deviation is 0.1%-0.3%. The monthly job finding rate ($\frac{M^{UN}}{U}$) is around 25%-32% on average. For flows from out of the labor force there is disagreement across studies; the more recent studies indicate mean hiring rates ($\frac{M^{ON}}{N}$) at 1.3%-1.5% and standard deviation of 0.1%-0.3%. The monthly separation rate into unemployment (s^{NU}) is around 1.3%-1.5% on average, implying quarterly separation rates of around 4%; its volatility is around 0.1%-0.3% in monthly terms. The separation rate into out of the labor force is computed differently across the different studies with a monthly mean ranging from 1.5% to 3.2% and a standard deviation ranging from 0.2% to 0.5%.

There was an evolution over time in the interpretation of the findings from these data.

Initially, Blanchard and Diamond (1989, 1990) highlighted the finding that the amplitude of fluctuations in the flow out of employment is larger than that of the flow into employment. This, in turn, implies a much larger amplitude of the underlying fluctuations in job destruction than of job creation. Hence, changes in employment are dominated by movements in job destruction rather than in job creation. Another important finding was that there are sharp differences between the cyclical behavior of the flows between employment and unemployment on the one hand and the flows between employment and out of the labor force on the other. In particular, the NU flow increases in a recession while the NO flow decreases. They also found that the UN flow increases in a recession, while the ON flow decreases. Ritter (1993) found similar patterns and also a downward trend in gross job finding and separation rates that started around 1984.

In a later study, Bleakley, Ferris, and Fuhrer (1999) reinforced these conclusions, finding that the flows into employment move around during the business cycle, but not nearly as much as the flows out of employment. Indeed, once the trend is removed, the flows out of employment have more than twice the variance of the flows into employment. They, too, note a trend decline in flows in and out of employment since the early 1980s. Fallick and Fleischmann (2004) studied employment to employment flows. They find that they are large; on average, 2.6 percent of employed workers leave one employer for another each month – about two-fifths of the total number of employer separations. This flow is about the same size as the NO flow and double the NU flow. Similarly, about two-fifths of the workers acceding to new employers did so straight from a previous employer.

More recently, three authors have presented a new and dissenting picture of worker flows, different from the one presented above. Hall (in the 2005b paper and a number of related ones) develops estimates of separation rates and job-finding rates for the past 50 years, using historical data informed by the detailed recent data from JOLTS. He finds that the separation rate is nearly constant while the job-finding rate shows high volatility at business-cycle and lower frequencies. He finds supporting evidence in CPS data, in Survey of Income and Program Participation (SIPP) data, and in the work reviewed below. He concludes that this necessitates a revised view of the labor market: during a recession unemployment rises entirely because jobs become harder to find. Recessions involve no increases in the flow of workers out of jobs. Another important finding from the new data is that a large fraction of workers departing jobs move to new jobs without intervening unemployment. Shimer (in the 2005b paper and related ones) uses CPS data to compute measures of job finding and separation rates, adjusting for time aggregation. He finds that the job finding probability is strongly procyclical and the separation probability is nearly acyclical, particularly during the last two decades. He shows that these results are not due to compositional changes in the pool of searching workers, nor are they due to movements of workers in and out of the labor force. He concludes that the results contradict the conventional wisdom, elaborated above. If one wants to understand fluctuations in unemployment, one must understand fluctuations in the transition rate from unemployment to employment, not fluctuations in the separation rate. Nagypal (2004) finds that job-to-job flows are vast: more than half of all prime-age full-time workers who separate from their employer between two monthly interviews are employed in the second month with a new employer, and over 70% are employed with a new employer conditional on not leaving the labor force. Overall, almost 7% of workers separate from their employer in any given month. 40% of these separations are to jobs at new employers, somewhat fewer than 20% are separations that result in unemployment, while almost 41% of separations result in withdrawal from the labor force. She also finds that there are strong reversals in flows out of the labor force. This has implications for whether one maintains the distinction between the state of unemployment and out of labor force as separate labor market states. One argument for finding the distinction between unemployment and out of labor force ambiguous is that there are large flows into employment from both non-employment states. The finding here is that almost half of the ON flows can be explained by very short spells of withdrawal from the labor force between two employment spells, and hence the "true" flows from out of the labor force into employment are overstated by the flows measured based on two months' of matched data. Nagypal documents that most of the variation in the employment-to-unemployment transition rate is due to the fact that while roughly the same number of workers separate from employers in a boom as in a recession, the fraction of them that immediately take up a new job (hence experience a job-to-job transition) is significantly lower in a recession.

This view has met with counter arguments. Davis (2005), in discussing Hall (2005b), argues that the cyclical behavior of job loss and worker displacement remains a key issue for macroeconomic analyses of labor market fluctuations. Based on his analysis of the data, he concludes that

Hall understates the volatility and cyclical movements in the total separations rate and exaggerates cyclical movements in the job-finding rate. He presents observations about the cyclical behavior of unemployment inflows and outflows, p indicating a different characterization of the job separations rate. The argument is that either the separations rate exhibits considerable counter-cyclical variation, contrary to Hall's claim, or the propensity of separated workers to become unemployed rises sharply in recessions. Another argument is that a lower job-finding rate per se does not raise measured unemployment inflows by enough to explain the data. Davis also posits that Hall's focus on the total separations rate is misplaced, as layoffs are strongly counter cyclical, while quits are strongly pro cyclical. The former become unemployed at a higher rate, experience longer unemployment spells, and have inferior post-separation earnings paths. Davis, Faberman and Haltiwanger (2005), studying new sources for job and worker flow data, uncover highly nonlinear relationships of worker flows to employment growth and job flows at the micro level, lending support to these claims. Yashiv (2006b) re-examines the data from both the earlier and the more recent studies, finding that while flows between employment and unemployment are measured similarly across studies, there are significant disparities in accounting for the flows between employment and the pool of workers out of the labor force. Comparing net employment growth predicted by these measured gross flows to actual values reveals problems with most of the series. At best the predicted values are correlated 0.7 with the actual values and account for 45% of their variance. He also finds that the volatilities of total flows into employment and out of employment are roughly the same; this fact as well as further analysis, contradicts the notion of a relatively stable separation rate.

4.3 Link with Job Flows

There is often discussion of the model in terms of job creation and job destruction. It is instructive to compare the worker flows discussed above to job flows. Davis and Haltiwanger (1999b) discuss both kinds of flows, noting some important distinctions (the following uses their definitions). First, consider worker flows concepts. Gross worker reallocation equals the number of persons who change place of employment between two consecutive periods, while worker turnover measures the gross number of labor market transitions. Worker turnover exceeds worker reallocation for two reasons. One is that job to job movements induce two transitions for one transiting worker. The other is that worker turnover measures often include all separations and accessions that occur during an interval of time, whereas worker reallocation measures typically reflect changes in employment status between two discrete points in time. Second, consider job flows concepts. Gross job reallocation at time t is the sum of all business unit employment gains and losses that occur between date $t-1$ and t. Hence it is the sum of job creation and job destruction. Third, consider the relations between worker flows and job flows. Job reallocation measures the reallocation of employment positions across establishments between two points in time, whereas worker turnover measures the accumulated employment transitions experienced by workers over a given time interval. Worker turnover is necessarily larger than job reallocation (turnover), since every instance of job turnover necessarily generates, at least, an equal amount of worker turnover. Thus, Davis and Haltiwanger (1999b, p. 2755) report that job reallocation accounts for about 35%-46% of worker turnover in quarterly U.S. data.

The magnitudes of job flows are reported in Table 2 in Davis and Haltiwanger (1999b, p.2722). Economywide annual job reallocation rates (as percentages of employment) are in the 20–25 percent range for Canada, France, Italy, and the United States; the figures for the U.K., Germany, the Netherlands and Norway are around 15-16 percent, while Australia and Denmark are at around 30 percent.

Some papers studied Europe-U.S. differences in this context. Bertola and Rogerson (1997) note that there is no evidence that *job* reallocation rates are substantially smaller in continental Europe than in the United States. Pries and Rogerson (2005) discuss the evidence on cross-country differences in *worker* turnover and find a difference. The most comprehensive measures of worker flows come from administrative records such as unemployment insurance or social security. On the basis of such records, Contini (2002) reports annual worker turnover rates in the 40–60 percent range for several countries in continental Europe. In U.S. data, Burgess et al. (2000) provide estimates using unemployment insurance records for Maryland and find an annual worker turnover rate of roughly 125 percent. Recently available data from the Census Bureau for several other states covering a shorter time period indicate that the figures for Maryland are typical for the U.S. economy. These measures suggest that worker turnover in the United States is between two and three times larger than in Europe. There are, however, lower estimates: Blanchard and Diamond (1989) estimate a worker turnover rate of 76 percent, and, on the basis of very different information, Pries (2004) estimates a tenure profile for separation rates using the Current Population Survey tenure supplement, which also implies a steady-state worker turnover rate equal to 76 percent. Pries and Rogerson (2005) conclude that while job reallocation is very similar in the United States and continental Europe, a conservative reading of the evidence suggests that worker flows in the United States exceed those in Europe by a factor of at least 1.5 (and possibly up to a factor of 2 to 3).

4.4 Matching Function Estimation

Estimation of the matching function has been widespread. Petrongolo and Pissarides (2001) provide a comprehensive survey of much of this estimation work, finding the following main features: (i) the prevalent specification is Cobb-Douglas with the flow of hires as the dependent variable and the stocks of unemployment and vacancies as the RHS variables; (ii) usually CRS is found, though some studies, such as Blanchard and Diamond (1989) and Yashiv (2000), produce evidence in favor of IRS; (iii) many studies have added other variables – such as demographical or geographical variables, incidence of long term unemployment, and UI – finding some of them significant, but not changing the preceding findings; (iv) these general patterns are robust across countries and time periods.

These studies suffer, though, from many problems: data quality (especially vacancy data are often of mediocre to poor quality, for example, using an index of Help Wanted Ads rather than number of job vacancies); difficulties in getting consistent measures of the different variables (for example, inclusion or non-inclusion of job to job movers); simultaneity (hiring flows deplete the stocks causing a negative correlation between the explanatory variables and the error term, see Berman (1997)); and serious aggregation issues (geographical and temporal).

Recent literature has begun to address some of these issues. Coles and Smith (1998) and Gregg and Petrongolo (2005) provide evidence according to which stock-flow matching functions perform better than random matching formulations. By taking the stock-flow approach (see Section 3.3 above), the time aggregation issues are dealt with more seriously. The findings are that indeed stock-flow mechanisms are important (higher matching rates for inflows rather than for stocks, higher initial matching probabilities) and their omission biases the estimates of matching function coefficients.

4.5 Structural Estimation

Much of the literature has focused on the estimation of the matching function, as discussed above. There are a few papers that relate to the estimation of a broader specification of the model.

Feve and Langot (1996) study the empirical performances of three models of the business cycle: a canonical Walrasian RBC framework, its extension to the case of a small open economy, and a version of this model with search and wage bargaining. Most structural parameters of the models are estimated using GMM with French data, with the other parameters calibrated. The authors then compare the moments of the estimated models to the data, finding that only the third model is able to generate theoretical moments that match their empirical counterparts.[9]

Yashiv (2000) uses Israeli data to structurally estimate the model. The paper shows that the aggregate search and matching model is not only theoretically appealing but also has substantial empirical content. It corroborates the search and matching model's approach whereby vacancy creation and hiring (in the case of firms) and search intensity (in the case of workers) may be

[9] This analysis is somewhat similar to those of Merz (1995) and Andolfatto (1996) reviewed below, with the differences being that the latter authors study the U.S. economy and do not base their model parameters on estimation but rely on various other sources, some of them microeconometric studies.

accounted for by an intertemporal optimization approach with convex search costs. It is able to quantify the relevant "asset values" of the match from the point of view of both firms and workers. The congestion and trading externality effects of search are quantified and shown to covary negatively with the relevant hazard rates. Plugging in the model's estimated parameters into a partial equilibrium model and simulating, it demonstrates the usefulness of the model in accounting for the dynamics in unemployment. More specifically, three equations are estimated: (i) The firm's F.O.C, yielding estimates of the costs of hiring the marginal worker or, in other words, the asset value of the match for the firm. The finding is that it ranges between 12 percent and 22 percent of average output per worker across specifications, equivalent to week to two weeks of wage payments. (ii) The worker's F.O.C determining search intensity. The estimated search costs are found to be around 40 to 65 percent of monthly wages on average. (iii) The matching function for both a Cobb-Douglas specification and a trans-log specification. The results show that CRS is rejected with the evidence in the Cobb-Douglas case for increasing returns to scale (IRS) in the order of 1.3.

As mentioned (see Sections 3.1 and 3.6 above), Merz and Yashiv (2005) structurally estimate the optimality conditions for firms decisions in U.S. data, allowing for costly hiring and investment, the former through vacancy creation. The estimates show a good fit of the data, demonstrating that a convex function that allows for the interaction of hiring and investment costs, is both necessary and useful. They find that total hiring and investment adjustment costs are 2.3% of GDP. The marginal costs of hiring in terms of average output per worker are 1.48 (value at sample mean point), roughly equivalent to two quarters of wage payments.

An alternative to structural estimation are calibration-simulation studies that set up the model using specific functional forms, assign values to the parameters, specify the driving shocks, and then simulate the model's second moments comparing them to the data. By their very nature, these studies are geared to explain business cycle behavior. In the next section. I therefore review these models, within the context of discussing the issue of how search and matching model contribute to our understanding of business cycles..

5 Business Cycle Analysis

Search and matching models have become key elements in models that seek to explain cyclical fluctuations in aggregate economic activity. At the same time that the basic model was being formulated in the early 1980s, there were major developments in business cycle research, with the advent of real business cycle models. Given the focus in the search and matching model on the "real" side of the economy, and its use of optimizing agents with rational expectations and equilibrium concepts, the standard model fits well with the RBC research program. Indeed, in the 1990s a number of studies showed its empirical usefulness in this context. More recently, however, some questioning has emerged with respect to the model's ability to match the data and various modifications and extensions are being explored to cater for that. Concurrently, the model is also used in conjunction with other models of the business cycle. As there is by now a voluminous literature on this topic, in what follows, I survey the main contributions in chronological order, as each has built on the previous contributions to make its point. The emerging picture is a complex one, with both successes and failures.

5.1 Early Contributions

Within the framework of the standard model presented in Section 2, Pissarides (1985, 1987) is an analysis of cyclical behavior. This analysis did not pursue the development of a full model of the business cycle, but rather aimed at explaining the dynamic behavior of unemployment, vacancies, and wages, ignoring capital. The analysis tried to match the cyclical stylized fact whereby when the economy is off the Beveridge curve it traces anticlockwise loops around the curve. The dynamic system is a saddlepoint, arising because one of the variables, unemployment, is sticky and stable, whereas the other, vacancies, is forward-looking and unstable. Firms treat vacancies as an asset; it is the price that has to be paid now in order to attract workers in the future. The expected arrival of workers is the rate of return on the asset held by the firm and, as with other assets, there is an instability inherent in the supply of vacancies. If the arrival rate of workers is expected to fall, the firm wants to have fewer vacancies when the fall takes place. It, therefore, endeavors to reduce its vacancies by hiring its workers before the expected fall. But to hire more workers sooner the firm needs to open up more vacancies. Thus, an expected fall in the arrival rate of workers leads to more vacancies coming into the market and to an immediate fall in the arrival rate of workers to each vacancy. The expected changes in the arrival rate of workers play the role of expected capital gains or losses on the firm's outstanding vacancies. This implies that vacancies overshoot their equilibrium value when an adjustment is expected to take place. Adjustment then takes place along the saddlepath, with constant market tightness and falling unemployment, until there is convergence to equilibrium. In this analysis, a rise in productivity causes an immediate rise in both market tightness and wages. The two variables jump to their new equilibrium. Firms open more vacancies to take advantage of the higher productivity, setting in motion unemployment dynamics, which move the economy towards the new steady-state equilibrium. Thus, wages and tightness move in jumps in response to news about productivity changes, whereas vacancies and unemployment trace anticlockwise loops around the Beveridge curve. Although the loops have spikes due to the overshooting of vacancies, which is not a feature of the data, the out-of-steady-state dynamics are broadly consistent with the stylized observation of anticlockwise loops.

Other models of cyclical fluctuations with search were proposed by Wright (1986) and Howitt (1988). Wright (1986) demonstrated how unemployment persistence can be generated even by i.i.d shocks due to search. The essential mechanism that generates this result is that workers sometimes choose to wait for a better wage offer, staying unemployed. Howitt (1988) constructed a model that features persistent involuntary unemployment, inefficient equilibria, and employment fluctuations with little real wage movement, without resorting to nominal rigidities, unexploited gains from trade, or implausibly large labor supply elasticity. The model uses a Lucas-type islands economy, with costly search and recruiting with transactions externalities. The author's point was to show that these results are possible even without using the cited undesirable assumptions. This is so due to the presence of search frictions in the labor market.

5.2 RBC Models

A number of papers have shown that the model is useful in accounting for business cycle facts within the RBC approach. The papers by Merz (1995) and Andolfatto (1996) showed that incorporating the search and matching model in the RBC framework improves on the performance of the latter model. The improved results consist of the following: productivity leads employment, as in the data, because the presence of frictions affects the dynamics of labor adjustment; the model conforms the higher volatility of total hours relative to wages, as found in the data; the persistence of employment and unemployment matches the data better; and the dynamics of output in the model are different from the assumed impulse dynamics. With the wage not equal to marginal productivity, the labor share in income is no longer constant but is counter-cyclical, as in the data. However, there are remaining problems on other dimensions: the model underpredicts the volatility of vacancies in the data; productivity remains more strongly pro-cyclical than it is in the data, though the problem is mitigated relative to the standard RBC model; and the model fails to produce the strongly negative correlation between unemployment and vacancies, the 'Beveridge curve' (in fact, under some specifications, it yields a positive correlation).

Den Haan, Ramey and Watson (2000) have additionally considered endogenous job destruction. They showed that cyclical fluctuations in the job-destruction rate magnify the output effects of shocks, as well as making them much more persistent. Interactions between capital adjustment and the job-destruction rate play an important role in generating persistence. Propagation effects were shown to be quantitatively substantial when the model is calibrated using job-flow data, and incorporating costly capital adjustment leads to significantly greater propagation.

5.3 Reallocation in Recessions

Barlevy (2002) uses on the job search and elements of the models by Mortensen and Pissarides (1994) and Pissarides (1994) to study the issue of job reallocation in recessions. The background for his work is the Schumpeterian notion that recessions are times when resources can be reallocated to more efficient use. The work of Caballero and Hammour (1994), as a notable example, had previously shown that recessions have a "cleansing effect." This idea seemed to have support in the data on increased job reallocation in U.S. manufacturing during recessions (see Davis and Haltiwanger (1999 a,b)). Barlevy (2002) claims that while there is such an effect with the closing down of inefficient jobs in recessions, there is a contradictory "sullying effect" at the same time. The latter is due to the fact that during recessions workers reallocate into their more productive employment more slowly and the mass of the job distribution shifts towards matches with lower surplus. Hence, as the economy cleanses out its most inferior matches, more workers are stuck in mediocre matches, and fewer high quality matches are created. He undertakes a simulation exercise suggesting that the sullying effect is the quantitatively more important effect.

5.4 Recent Questioning

More recently, some authors have raised questions with respect to the ability of the model to account for business cycle facts.

Cole and Rogerson (1999) found that the model can account for business cycle facts only if the average duration of unemployment is relatively high (9 months or longer), substantially longer than in the data. Veracierto (2002) has shown that the model fails to simultaneously account for the observed behavior of employment, unemployment, and out of the labor force worker pools. Analyzing the RBC model with search and matching that makes an explicit distinction between these states, he finds that the model has serious difficulties in reproducing the labor market dynamics observed in U.S. data. In particular, employment fluctuates as much as the labor force while in the data it is three times more variable, unemployment fluctuates as much as output while in the data it is six times more variable, and unemployment is acyclical while in the data it is strongly counter-cyclical. An underlying reason is that search decisions respond too little to aggregate productivity shocks. Fujita (2004) conducted empirical tests showing that vacancies are much more persistent in the data than the low persistence implied by the model. Costain and Reiter (2003) argue that in a RBC model with matching, procyclical employment fluctuations occur when match productivity rises in booms. At the same time an increase in unemployment benefits negatively affects employment by reducing the match surplus. They then show that the standard model implies a close relationship between the two, but that this is strongly at odds with data. To reproduce business cycle fluctuations, matching must be quite elastic with respect to the surplus; but to reproduce the observed effects of unemployment benefits policies, matching must be, at the same time, more inelastic.

Two authors have challenged the standard model more fundamentally. Shimer (2005a) showed that the standard search and matching model can explain only a small fraction of cyclical fluctuations in the labor market, most notably those of unemployment and vacancies. The key reason for this result is that the standard model assumes that wages are determined by Nash bargaining, which in turn implies that wages are "too flexible." Thus, for example, following a positive productivity shock wages increase, absorbing the shock and thereby dampening the incentives of firms to create new jobs. In the U.S., the standard deviation of the vacancy-unemployment ratio is almost 20 times as large as the standard deviation of average labor productivity, while the model predicts that the two variables should have nearly the same volatility. A shock that changes average labor productivity primarily alters the present value of wages, generating only a small movement along a downward-sloping Beveridge curve. Hall (2005 a,b and related papers) has built on the findings of Shimer (2005a) and on new jobs data from JOLTS (see sub-section 4.2 above) to argue the following: rather than thinking of unemployment as some transitory deviation from equilibrium (including from a 'natural rate' of unemployment), one should view the labor market as being in continuous equilibrium, which is stochastic and dynamic. When the labor market is tight, employers devote substantial resources to recruiting workers and so job-finding rates for the unemployed are high. When the market is slack, employers recruit less aggressively and job-finding rates are low. Moreover, transitions from strong markets with low unemployment and high vacancies to weak markets with high unemployment and low vacancies seem to occur without large measurable changes in driving forces. Rather, small shocks stimulate large responses of unemployment. To account for the observed facts, and in particular for the high volatility of unemployment, vacancies, and the job finding rate, and the relative stickiness of wages, the following need to be considered: first, a formulation of wage setting that is consistent with (i) no unrealized bilateral gains to trade (i.e., no worker-employer pair has an unexploited opportunity for mutual improvement) and (ii) wages that are relatively unresponsive to shocks to the value of a match. Hall (2005a) proposes one such formulation, an equilibrium sticky-wage model, based on wage determination in terms of a Nash (1953) demand game or auction. He explores different equilibrium selection rules to pin down the wage within the bargaining set. Second, one needs to study reasons for changes in recruiting efforts by employers so as to explain the volatile job finding rate. Hall (2005b) discusses a number of models that can account for these dynamics, including sticky wages and informational asymmetries in the firm-worker relationship.

5.5 Recent Replies

Several authors have addressed the critique of the afore going papers.

Mortensen and Nagypal (2005) review in detail the elements of the model that may be 'responsible' for the failures found in matching the data and survey some recent work in this context. They make several points: first, they show that the only important parameters determining the response of the vacancy-unemployment ratio to a productivity shock are the elasticity of the job-finding rate and the opportunity cost of employment. The former is given by the relevant parameter of the matching function and the latter by the modelling of unemployment income. They offer some discussion of these parameters, disputing the magnitudes used by Shimer (2005a). Second, they argue that a flexible wage per se is not the principal problem with the model. It is the large difference between labor productivity and the wage (i.e., the value of $\xi - w$ in the notation of Section 2), implied by the assigned magnitudes of the parameters, that is responsible for the lack of amplification of productivity shocks. Even if the wage were rigid, its level must be such that the future flow of quasi-rent attributable to the creation of a new job is very small if the model is to account for the volatility of the vacancy-unemployment ratio observed in the data. In other words, a wage that only weakly responds to productivity shocks can account for the observed volatility in the job-finding rate but only if its level is high enough. This discussion implies that various elements that potentially influence the value of $\xi - w$ are important. Third, and following the last point, they augment the model by allowing for capital costs, countercyclical involuntary separations, and the less cyclical wage implied by a strategic bargaining outcome. After accounting for all these facts, they find that the amended model can explain about 40% of the volatility in the job-finding rate relative to that of productivity observed in Shimer's CPS data.

Hagedorn and Manovskii (2005) argue that Shimer's choice of the opportunity cost of employment is too low because it does not allow for the value of leisure or home production forgone when employed as well as an unemployment benefit. They calibrate both the opportunity cost of unemployment and the wage share parameter to match the cyclical response of wages and the average profit rate. Using this different calibration, the model does match the data. The problem with this analysis – as pointed out by Mortensen and Nagypal (2005) – is that the authors assume an extremely low value (less than 2%) for the gap between wages and unemployment income.

Yashiv (2006 a,b) shows that if there is data-based modelling of the separation rate and if convex hiring costs are allowed for, then for the most part the model fits U.S. labor market data relatively well. This includes capturing the high persistence and high volatility of most of the key variables, the negative co-variation of unemployment and vacancies (the 'Beveridge curve'), and the behavior of the worker job finding rate. He argues that the lack of fit found in the literature is due to the use of a linear hiring cost function instead of a convex one and due to different stochastic properties assigned to the separation rate. When moving from convex to linear costs, all the persistence statistics decline, getting further away from the data; employment volatility falls, wages become counterfactually more volatile, and hiring and separation rates become more disconnected. The other key element is the role played by the separation rate. As it is a variable with a relatively high mean, it is the main determinant of the relevant discount factor of the match present value; as it has relatively high volatility and persistence, it makes this present value of the match volatile and persistent. This in turn engenders the volatility and persistence of vacancies, hiring, and unemployment. However, Yashiv, too, finds that the model is unable to account for real wage behavior.

5.6 Summing Up

The empirical picture that emerges from Sections 4 and 5 is mixed. On the one hand, there is much evidence in favor of the model, from matching function estimation, through structural estimation of the whole model, and up to its incorporation in RBC and New Keynesian models, improving their fit. It has encouraged the collection, computation, and analysis of gross flows data and has been able to account for them. On the other hand, there are papers pointing to difficulties with the empirical fit, and in particular the ability of productivity shocks to account for vacancy and unemployment fluctuations in the data. There also seems to be agreement that real wage behavior is not well explained. Estimation of the matching function can also be criticized on both theoretical and empirical grounds.

Moreover, there is still debate as to what is really needed: a different formulation of shocks, or fundamental changes in the structure of the model, or more realistic parameter values in the current structure? This exploration is likely to be informed by the development of additional data sets, such as data on gross worker and job flows, and matched employer-employee data sets.

6 Other Macroeconomic Issues

I briefly examine other macroeconomic issues that have been treated using the search and matching model.

6.1 Growth

The effects of growth in the current context are that old jobs are destroyed when new technologies arrive, but these are subsequently replaced by new, more productive ones. Hence new technology stimulates job creation at a given wage. Indeed faster growth reduces unemployment in Pissarides (2000, Chapter 2) due to its positive effect on the present value of the match. However, Aghion and Howitt (1994) propose an additional consideration. They examine the effects of growth in a variant of the standard model, whereby growth arises from the introduction of new technologies that require labor reallocation for their implementation. They highlight two competing effects on long run unemployment. The first is a capitalization effect, whereby an increase in growth raises the capitalized returns from creating jobs, and consequently causes a reduction in equilibrium unemployment, as in Pissarides (2000). The second is a creative destruction effect, whereby an increase in growth lowers the duration of the job match, thereby causing an increase in equilibrium unemployment both through the rise in job separation and through the discouragement of the creation of job vacancies.

Mortensen and Pissarides (1998) embed this discussion in a general equilibrium model in which the number of jobs is determined by the interaction of job-creation and job-destruction decisions. In their model, new technology embodied in capital equipment can be adopted either through destruction of existing jobs and the creation of new ones, or by costly renovation, updating the job's equipment. Under the assumption that the destruction of jobs generates worker layoffs, they show that higher productivity growth induces lower unemployment when renovation costs are low, but that the response of employment to growth switches from positive to negative as the cost of updating existing technology rises above a unique critical level.

6.2 Inequality

Models of search that explain wage inequality are at the heart of the micro-based search literature, which is briefly discussed in the next section. In the context of the macroeconomic literature there is much less treatment of this issue. The notable exceptions are the models with heterogeneity and with on the job search, and in particular, the models of Acemoglu (1999), Albrecht and Vroman (2002), and Moscarini (2005) discussed above. A paper that is specifically devoted to this issue in the macro context is Wong (2003). It asks whether the standard model with productivity changes can explain wage inequality in the United States during the 1970s and 1980s. The main finding is that the model produces counterfactual results. The main source of failure seems to be the exogenous matching function and/or the exogenous surplus share, neither of which allows firms to use wage policies (such as contracts) to direct workers' search.

6.3 Policy Implications

Much of the literature on policy implications of the model deals with two sets of issues:

(i) The effects of specific policy schemes, such as unemployment benefits, payroll taxes, firing taxes, hiring subsidies, and minimum wages.

(ii) U.S. – Europe unemployment differences in labor market outcomes, such as unemployment incidence and duration, employment growth, wages, earnings inequality, and job and worker turnover.

There is a large number of papers on these issues. In what follows I look at key studies; these studies cite and review previous studies, which are not surveyed here.

Mortensen and Pissarides (1999c) use their model with endogenous separations (Mortensen and Pissarides (1994)) to show that skill-biased shocks can explain why and how different unemployment insurance (UI) and employment protection (EP) policies can lead to the differential U.S and European wage and employment responses.[10] They use the model to derive a convex, negative relationship between unemployment rates and skill levels. This relationship is more convex with relatively high UI and EP levels, as is the case for Europe. High UI is associated with a relatively high level of unemployment; high EP, in the form of a high implicit firing tax, is associated with a

[10] See also Millard and Mortensen (1997) for an earlier treatment.

relatively low level of unemployment. They then interpret a skill-biased shock as a mean-preserving increase in the spread of labor productivities across workers, leading to higher average unemployment. Under the European policy parameters, unemployment rises more because of the higher convexity.

Marimon and Zilibotti (1999) consider a model with two-sided, ex-ante heterogeneity. They consider the effects of skill-biased technological change with different levels of unemployment benefits. The latter are perceived as a subsidy for the unemployed to search for a suitable job. When benefits are too high workers become too selective, rejecting matches that would have been socially efficient. There is a tradeoff between unemployment and mismatch. When the economy is hit by a skill biased technological shock, the European-type of economy with high benefits experiences higher unemployment with longer average duration but also higher worker productivity growth and less wage inequality.

Yashiv (2004) seeks to address the following questions: given frictions, how does policy affect key labor market outcomes in the steady state and what effects does it have on their business cycle properties? More specifically, the paper explores the decline in unemployment following the implementation of different policy measures, the "cost-effectiveness" of each measure, and the changes in the stochastic behavior of unemployment and other key outcomes that follow each policy. He finds that hiring subsidies and unemployment benefits have substantial effects on labor market outcomes, while employment subsidies and wage tax reductions do not. Thus, provision of hiring subsidies or reduction in benefits have important consequences for the major variables. These results are consistent with the view that high European unemployment is due to high hiring costs and generous unemployment benefits. Policy has effects on the stochastic behavior of key variables: measures that reduce unemployment also reduce its persistence and increase the volatility of vacancies. An implication of these results pertains to economies with laws and bureaucratic procedures that make hiring effectively more costly – such as some of the European countries. The analysis implies that these economies, compared to those without such laws and procedures, should expect a higher rate of unemployment with longer duration and more persistence, and with all key variables less volatile and less cyclical.

Pries and Rogerson (2005) examine four policies in the model described in Section 3.5 above – minimum wages, unemployment benefits, dismissal costs, and taxes – and assess the quantitative impact of European-style policies on allocations and welfare in a calibrated version of their model. They find that minimum wages and dismissal costs both significantly affect worker turnover. Their analysis also shows that interactions between the various policies can be significant: the effects of minimum wages on hiring practices are exacerbated by the presence of payroll taxes, even though payroll taxes by themselves have very little effect. The model can account for almost half of the observed differences in worker turnover rates between the United States and continental Europe (reviewed above, see Section 4.3). The welfare costs of lowering worker turnover via changes in hiring practices are significant. The steady-state welfare cost of a policy that lowers worker turnover by 20 percent exceeds 2.4 percent of output. Although more stringent hiring practices increase the average match quality, they also necessitate that a greater fraction of output be devoted to recruiting.

Using a different modelling structure, a GE search framework without matching, Ljungqvist and Sargent (1998) study the interaction of greater economic turbulence and high unemployment benefits to explain the European experience. Workers accumulate skills on the job and lose skills during unemployment. The welfare economy is vulnerable to economic turbulence in that, following large shocks, the provision of generous benefits hinders the restructuring of the economy. This is so because laid off workers lack the incentives to quickly accept new jobs with new skills.

Using the class of models of directed search and wage posting (following Moen (1997)), Aceomglu and Shimer (1999) look at the efficiency of UI policy. They employ the following set up: firms make irreversible investments and post wages. Workers optimally search among posted wages. Risk averse workers wish to avoid unemployment and so the equilibrium is one with lower unemployment and wages. Unemployment insurance encourages workers to apply to high wage jobs with high unemployment risk. This boosts investment by firms, and the equilibrium has higher output (with higher unemployment risk), so UI enhances efficiency.

It should be noted (without review) that there is another strand of literature that look at the effects of policy on job reallocation, with some elements of search. This strand includes work by Hopenhayn and Rogerson (1993), Bertola and Rogerson (1997), and Alvarez and Veracierto (2001).

A different set of macroeconomic issues is treated by some recent papers which look at monetary policy using the search model. Walsh (2005) poses the following key questions: what accounts for the significant real effects of monetary policy shocks, and what accounts for the persistent and hump shaped responses of output and inflation in response to such shocks? He investigates these questions in a model that incorporates labor market search, habit persistence, sticky prices, and policy inertia. While habit persistence and price stickiness are important for the hump shaped output response and the long, drawn out inflation response, respectively, labor market frictions increase the output response and reduce the inflation response relative to an otherwise similar model based on a Walrasian labor market. In a similar GE model, Trigari (2004) structurally estimates a set of parameters characterizing the dynamics of the labor market. The results indicate that, when labor market search is incorporated into a standard New Keynesian model, the ability of the model to explain the response of output and inflation improves along a number of dimensions. Allowing for variation of the labor input at the extensive margin leads to a significantly lower elasticity of marginal costs with respect to output. This helps to explain the sluggishness of inflation and the persistence of output after a monetary policy shock. The ability of the model to account for the joint dynamics of output and inflation rely on its ability to explain the dynamics in the labor market. The estimated model can also explain the cyclical behavior of employment, hours per worker, job creation and job destruction, conditional on a shock to monetary policy.

Krause and Lubik (2005) show that in a baseline New Keynesian model, labor market frictions render real wage rigidity potentially irrelevant for the dynamics of inflation. The reason is the importance of wage rigidity for the dynamics of the labor market. A rigid real wage generates a Beveridge curve and cyclicality of vacancies and unemployment that is consistent with the data, as described in Section 5. But the resulting volatility of labor market tightness affects real marginal costs and thus inflation dynamics through the New Keynesian Phillips curve. As one component of real marginal costs, wages, becomes less volatile, the other component, hiring and job creation costs, becomes more volatile. Thus, the mechanism emphasized by Hall (2005a) and Shimer (2005a) that helps the search and matching model fit the facts, appears to have a neutralizing effect in sticky price models. In the monetary economics context the following findings are important: in the presence of labor market frictions, the relevant measure of marginal cost is explicitly dynamic. It represents the marginal contribution of an additional unit of labor to the present discounted value of profits which is distinctly different from current real wages. This suggests that empirical studies of the New Keynesian Phillips curve that use simple marginal cost measures or the labor share are misspecified.

7 Link with the Search Literature

This section briefly references the wide array of other search models.

There are search models that share some common features with the model described here, yet differ from it on several dimensions. Closest in spirit, perhaps, is the Lucas and Prescott (1974) model. This is an "islands" model of spatially separated labor markets. Agents work at the market-clearing wage of their own market or move to another labor market. The frictions are due to the fact that moves between markets take time and there is unemployment for that reason. In equilibrium agents move to markets that experience positive productivity shocks, with bad productivity markets losing some of their labor. This model has no matching or bargaining, and wages are set competitively so they equal the marginal product. More recent models following this approach include Greenwood, MacDonald and Zhang (1996) and Gomes, Greenwood, and Rebelo (2001).

There is a vast micro-based search literature. Referring back to the classification of the Rogerson, Shimer, and Wright (2005) survey mentioned in the introduction, this is the third class of models, relying on random matching and wage posting. The latter survey, and the surveys by Mortensen (1986), Devine and Kiefer (1991), Mortensen and Pissarides (1999b), and Eckstein and van den Berg (2005) provide good overviews. The model with search, random matching, and bargaining surveyed in the current paper differs in three major ways from the micro-based models: there is often no match-specific heterogeneity, the job arrival rates are functions of unemployment and vacancies through the matching function, and there is ex-post wage bargaining rather than wage posting. Because of the first property there is only one equilibrium wage in the basic model, though the more advanced versions with heterogeneity do feature a wage distribution. The micro-based models are designed to explain wage distributions, both offered and actual (accepted), and the distributions of employment and unemployment spells. Thus, this literature focuses on modelling heterogeneity, the optimality of firm wage posting policy and of worker job acceptance, on the job search, and the effects of search decisions on the wage distribution and on the unemployment spell distribution. As can be seen in the current survey, some of these issues are now being treated in the matching and bargaining literature as well. But, as indicated, the latter takes a different approach to the modelling of the way workers and firms meet (matching) and set wages (bargaining).

8 Open Questions and Conclusions

The survey has demonstrated that there is a substantial number of issues still open that call for further research. In fact this statement pertains to almost every aspect of the model. There is a need to broaden the firm optimality problem, taking into account the adjustment of other factors of production, as well as the associated costs and lags. Likewise, workers decisions on search intensity seem to be under-researched, in particular empirically. A great need exists for the further modelling of firm and worker heterogeneity. There is ample empirical evidence to show the importance of heterogeneity in macroeconomic contexts and it underlies the micro-based search models. The modelling thus far is often stylized (such as 'good' and 'bad' jobs) and typically has not catered for empirical features, such as highly skewed productivity distributions. On the worker side, labor force participation decisions, reflecting underlying dispersion in preferences and in skills, have not been adequately dealt with. These modelling issues have a bearing on the matching function. The latter has received much empirical attention, but there is insufficient work on its micro foundations, especially when recognizing heterogeneity in an explicit way. The part of the model that came under the strongest critique is wage determination, where there is an increasing recognition that the current paradigm of Nash bargaining needs modification or replacement. This links up with the empirical performance of the model. Recent work has posed doubts with respect to the ability of the model to match the facts and has found that wage behavior is a particularly weak element of the model. At the same time, there is a need to sort out the relevant data issues, given that there is no agreement on the interpretation of the some of the main data series, such as job finding rates, and hiring and separation flows. All of these modifications are sure to influence the empirical performance of the model when embedded in general equilibrium frameworks. The emergence of data sets of worker flows and job flows and matched employer-employee data is likely to facilitate the empirical endeavor.

Despite the fact that much research still needs to be undertaken, it is clear that the model has the ability to explain labor market outcomes, including their dynamics. It enhances our understanding of business cycles and of the effects of policy. It points to the data that we need to consider when studying cyclical fluctuations or the evolution of unemployment. Given the model's richness, it is not surprising to find, as pointed out at the outset, that it has become a key and important feature of macroeconomic modelling.

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