

Exogenous vs. Endogenous Separation

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Abstract

This paper assesses how various approaches to modelling the separation margin affect the ability of the Mortensen-Pissarides job matching model to explain key facts about the aggregate labor market. Allowing for realistic time variation in the separation rate, whether exogenous or endogenous, greatly increases the unemployment variability generated by the model. Specifications with exogenous separation rates, whether constant or time-varying, fail to produce realistic volatility and productivity responsiveness of the separation rate and worker flows. Specifications with endogenous separation rates, on the other hand, succeed along these dimensions. In addition, the endogenous separation model with on-the-job search yields a realistic Beveridge curve correlation, and it performs well in accounting for the productivity responsiveness of vacancies and market tightness. When the Hagedorn-Manovskii calibration approach is used, the behavior of the job finding rate, vacancies and market tightness becomes more realistic, but the volume of job-to-job transitions in the on-the-job search specification is essentially zero.

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1 Introduction

In its complete form, the Mortensen-Pissarides job matching model (henceforth MP model) endogenously determines both the match creation and separation margins.¹ While researchers agree that match creation is appropriately viewed as endogenous, there is little consensus as to the proper treatment of the separation margin. Papers such as Cole and Rogerson (1999), Fujita (2003, 2004), Mortensen and Nagypál (2007b), Mortensen and Pissarides (1994), Pissarides (2007) and others allow match dissolution to be responsive to incentives facing the worker and firm. On the other hand, Costain and Reiter (2006), Fujita and Ramey (2007), Hagedorn and Manovskii (2008), Hall (2005), Hornstein, et al. (2006), Mortensen and Nagypál (2007a), Shimer (2005), Yashiv (2006) and others specify that matches break up at a rate that is exogenous and constant, affected by neither incentives nor cyclical factors. Mortensen (2005), Mortensen and Nagypál (2007a), Shimer (2005) and Yashiv (2006) consider a third possibility, namely that separation rates vary over time in a random manner, while Krause and Lubik (2006), Mortensen (1994, 2005), Nagypál (2005a,b), Pissarides (1994), Tasci (2006) and others allow for separation directly to new jobs.

This paper assesses how these various approaches to modeling the separation margin affect the ability of the MP model to explain key facts about unemployment, transition rates, worker flows and other variables. A discrete-time version of Pissarides' (2000) specification is calibrated at weekly frequency. Match separation is parameterized in four ways: (i) constant separation rate; (ii) exogenous separation rate following an AR(1) process; (iii) endogenous separation rate without on-the-job search (OJS); and (iv) endogenous separation rate with OJS. For the two specifications with endogenous separation, match-specific productivity factors follow a persistent stochastic process, i.e., the factors are not required to be i.i.d. over time, as in many previous papers. The model is solved using a nonlinear method that parameterizes match surplus and market tightness (i.e., the vacancy-unemployment ratio) on a grid, and iterates backward to exploit stability of the backward dynamics.

In calibrating the model, the values of the workers' unemployment benefit and bargaining weight, as well as the elasticity parameter of the matching function, are set to standard values advocated by Mortensen and Nagypál (2007a). The calibration of the

¹Throughout this paper, the terms "separation" and "job finding" denote movements of workers between employed and unemployed status.

vacancy posting cost draws on survey evidence from Barron and Bishop (1985) and Barron, et al. (1997). Other parameters are chosen to match the mean monthly job finding and separation rates calculated by Fujita and Ramey (2006), who consider data from the Current Population Survey (CPS) over the 1976-2005 period. In addition, each of the three specifications with time-varying separation rates is calibrated to match the standard deviation of the separation rate observed in the Fujita-Ramey data. For the OJS specification, the cost of OJS is calibrated by matching the average job-to-job transition rate measured by Moscarini and Thomsson (2007) using CPS data.

Statistics calculated from simulated data for the four specifications are compared to corresponding statistics obtained from the Fujita-Ramey data. The results show, first of all, that the model with constant separation rates fares poorly in accounting for the volatility of key labor market variables. It does not, of course, explain the substantial variability of the separation rate observed in the data; nor does it generate anywhere near the empirical volatility of unemployment, a point stressed by Costain and Reiter (2006) and Shimer (2005). In addition, the variability of gross worker flows, both unemployment-to-employment (UE) and employment-to-unemployment (EU), is far too low in the constant separation rate model.

On the other hand, the three specifications with time-varying separation rates, which are calibrated to match the volatility of the empirical separation rate, each generate substantially greater volatility of unemployment and worker flows. In the model with OJS, for example, the standard deviation of unemployment equals 60 percent of its empirical value. Moreover, the three specifications match closely the standard deviations of UE and EU flows. Introducing realistic variability at the separation margin thus substantially improves the performance of the MP model in accounting for unemployment and worker flow variability.

In the data, the separation rate and the two worker flow variables exhibit substantial negative correlations with productivity. Both versions of the MP model with exogenous separation fail along this dimension, as they generate essentially no productivity comovement of separation rates and worker flows. The two versions with endogenous separation, however, exhibit realistic responsiveness of these variables to productivity. Endogeneity of the separation rate appears central to explaining the cyclical properties of the separation rate and worker flows.

The two endogenous separation specifications differ in their ability to account for the Beveridge curve relationship, wherein unemployment and vacancies display strong nega-

tive correlation. In the absence of OJS, the model with endogenous separation produces a counterfactually positive unemployment-vacancy correlation, due to fact that higher unemployment makes workers easier to find during downturns, stimulating the posting of vacancies. With OJS, however, downturns also imply a fall in the number of employed searchers, militating against the rise in unemployment. The unemployment-vacancy correlation becomes strongly negative in this case, matching closely the empirical value. Endogenous separation is therefore consistent with the Beveridge curve relationship when OJS is added to the model. Moreover, this specification captures the negative correlation between the job finding and separation rates seen in the data.

In summary, the endogenous separation specification with OJS implies empirically reasonable volatility and productivity responsiveness of unemployment, the separation rate and worker flows, along with realistic Beveridge curve and transition rate correlations. Each of the remaining three specifications fails decisively along one or more of these dimensions. This provides strong support for the OJS model as the most valid specification.

The results also show, however, that the MP model under the standard calibration does not produce realistic volatility of the job finding rate, irrespective of how the separation margin is modelled. The empirical standard deviation of the job finding rate is nearly six times the simulated value for each of the four specifications, and the comparison is similar for the productivity elasticity. This failure to generate realistic behavior at the job finding margin, which lies at the heart of the Hall-Shimer critique of the MP model, is thus not resolved by introducing realistic behavior at the separation margin.

The three specifications without OJS also deliver insufficient productivity responsiveness of vacancies and market tightness. In the OJS specification, however, these variables are much more responsive to productivity: the productivity elasticities of vacancies and market tightness in the simulated data amount to roughly 50 and 75 percent, respectively, of their empirical values. In the OJS specification, procyclical variation in the number of searching workers causes vacancies to be more responsive to productivity at given levels of market tightness.

The MP model is further evaluated in terms of its ability to generate realistic dynamic interrelationships, as captured by cross correlations at various leads and lags. None of the four specifications reproduces the sluggish productivity responses of unemployment, the job finding rate, vacancies and market tightness that are seen in the data. As pointed out by Fujita and Ramey (2007), rapid adjustment of vacancies prevents the model from exhibiting realistic dynamics with respect to these variables. The OJS specification does,

however, demonstrate empirically reasonable dynamic patterns along the other dimensions considered, including the cross correlations between unemployment and vacancies, and between job finding and separation rates.

Hagedorn and Manovskii (2008) propose an alternative calibration strategy, drawing on empirical information on wages and profits, that raises the volatility of unemployment, market tightness and other variables in the constant separation rate model. To investigate the robustness of the current findings to this alternative, the constant separation rate and OJS specifications are suitably recalibrated. In line with Hagedorn and Manovskii's findings, this procedure yields much more realistic volatility of unemployment, the job finding rate, vacancies and market tightness. It does not, however, remedy the key failings of the constant separation rate model: in particular, the separation rate and worker flows continue to display unrealistic variability and productivity comovement. Moreover, in the OJS specification the volume of job-to-job transitions becomes essentially zero. This is because the worker's bargaining weight is very low under the alternative calibration, making OJS unattractive in nearly all circumstances.

Numerous previous papers have evaluated the properties of the MP model in dynamic stochastic equilibrium. Most closely related are Mortensen and Pissarides (1994) and Mortensen (1994). These papers calibrate and simulate endogenous separation versions of the standard MP model in continuous time, and stress the model's ability to explain facts about job creation and destruction in manufacturing. The latter paper also allows for OJS, and delivers countercyclical worker flows and a negative Beveridge correlation, consistent with the results obtained here.

More recently, Krause and Lubik (2006) and Tasci (2006) offer modifications of the MP model that incorporate OJS.² Both papers show that their models yield significantly greater unemployment volatility than does the standard constant separate rate specification, and they also obtain negative Beveridge correlations.³

²Krause and Lubik (2006) specify a constant rate of separation to unemployment, and introduce permanent productivity differences across jobs in order to elicit OJS. Tasci (2006) posits that each match undergoes an initial phase of learning about productivity, the outcome of which may induce endogenous separation.

³Menzio and Shi (2008) analyze worker flows and transition rates using a matching model that features directed search across labor submarkets, together with complete commitment of wage contracts. Their findings with respect to unemployment volatility and the Beveridge curve conform with those of Krause and Lubik (2006) and Tasci (2006). Moreover, they consider how failure to account for match heterogeneity biases the measured effects of productivity shocks.

Dynamic stochastic equilibrium versions of the MP model without OJS have been considered by Costain and Reiter (2006), Fujita (2003, 2004), Fujita and Ramey (2007), Hagedorn and Manovskii (2008), Shimer (2005) and Yashiv (2006). These papers either specify exogenous separation rates, or else introduce endogenous separation by means of match-specific productivity factors that follow i.i.d. processes. In comparison to the preceding papers, the present one highlights the behavior of the separation margin and the various approaches to modelling it. It also allows for match-specific productivity persistence and OJS.⁴

Finally, a number of papers have embedded the MP model into stochastic dynamic general equilibrium frameworks.⁵ This body of work focusses chiefly on dynamic propagation of aggregate technology and monetary shocks. An exception is Merz (1995), who combines the standard RBC model with a constant separation rate specification of the MP model to investigate the cyclical properties of unemployment and vacancies. In her simulated data, the standard deviations of unemployment and vacancies lie reasonably close to their empirical counterparts, suggesting that general equilibrium effects may have an important influence on the volatility of these variables.

The paper proceeds as follows. Section 2 introduces the four specifications of the MP model and constructs theoretical measures that correspond to the empirical data series. The calibration procedure and numerical solution method are discussed in Section 3, and results are presented in Section 4. In Section 5, the dynamic interrelationships of labor market variables are considered. Section 6 investigates the implications of the Hagedorn-Manovskii calibration approach, and Section 7 concludes.

2 MP Model

2.1 Basics

There is a unit mass of atomistic workers and an infinite mass of atomistic firms. Time periods are weekly. In any week t , a worker may be either matched with a firm or unem-

⁴Mortensen and Nagypál (2007b) consider the comparative statics of productivity in nonstochastic versions of the MP model with constant and endogenous separation. Consistent with the results obtained here, they find that allowing for endogenous separation significantly increases the elasticity of steady state unemployment with respect to productivity, but has a small effect on the elasticity of market tightness.

⁵These papers include Andolfatto (1996), Cooley and Quadrini (1999), Den Haan, Ramey and Watson (2000), Farmer and Hollenhorst (2006), Gertler and Trigari (2006), Hall (2006), Krause and Lubik (2007), Merz (1995), Rotemberg (2006) and Walsh (2003, 2005).

ployed, while a firm may be matched with a worker, unmatched and posting a vacancy, or inactive.

Unemployed workers receive a flow benefit of b per week, representing the total value of leisure, home production and unemployment insurance payments. Firms that post vacancies pay a posting cost of c per week. Let u_t and v_t denote the number of unemployed workers and posted vacancies, respectively, in week t . The number of new matches formed in week t is determined by a matching function $m(u_t, v_t)$, having a Cobb-Douglas form:

$$m(u_t, v_t) = Au_t^\alpha v_t^{1-\alpha}.$$

Thus, an unemployed worker's probability of obtaining a match in week t is $A\theta_t^{1-\alpha}$, where $\theta_t = v_t/u_t$ indicates market tightness. A vacancy obtains a match with probability $A\theta_t^{-\alpha}$. The value of v_t in each week is determined by free entry.

A worker-firm match can produce an output level of $z_t x$ during week t , where z_t and x and are aggregate and match-specific productivity factors, respectively. The aggregate factor is determined according to the following process:

$$\ln z_t = \rho_z \ln z_{t-1} + \varepsilon_t^z, \quad (1)$$

where ε_t^z is an i.i.d. normal disturbance with mean zero and standard deviation σ_z . Determination of x is discussed below.

Before engaging in production in week t , the worker and firm negotiate a contract that divides match surplus according to the Nash bargaining solution, where π gives the worker's bargaining weight and the disagreement point is severance of the match. Let $S_t(x)$ indicate the value of match surplus in week t for given x , and let U_t and V_t be the values received by an unemployed worker and a vacancy-posting firm, respectively. The worker and firm will agree to continue the match if $S_t(x) > 0$, while they will separate if separation is jointly optimal, in which case $S_t(x) = 0$. As the outcome of bargaining, the worker and firm receive payoffs of $\pi S_t(x) + U_t$ and $(1 - \pi)S_t(x) + V_t$, respectively.

Let x^h denote the value of the match-specific productivity in a new match. The unemployment and vacancy values satisfy

$$U_t = b + \beta E_t[A\theta_t^{1-\alpha} \pi S_{t+1}(x^h) + U_{t+1}], \quad (2)$$

$$V_t = -c + \beta E_t[A\theta_t^{-\alpha} (1 - \pi) S_{t+1}(x^h) + V_{t+1}], \quad (3)$$

where β is the discount factor. In free entry equilibrium, $V_t = 0$ holds for all t ; thus, θ_t is determined by

$$\beta A \theta_t^{-\alpha} (1 - \pi) E_t S_{t+1}(x^h) = c. \quad (4)$$

2.2 Exogenous separation

In the exogenous separation version of the MP model, $x = x^h$ is assumed to hold at all times and for all matches. At the end of each week, matches face a risk of exogenous separation. Let s_t denote the probability that any existing match separates at the end of week t . The exogenous separation probability is determined by

$$\ln s_t = \rho_s \ln s_{t-1} + (1 - \rho_s) \ln s + \varepsilon_t^s, \quad (5)$$

where ε_t^s is i.i.d. normal with mean zero and standard deviation σ_s .

Let $M_t(x)$ denote the value of a match in week t when the match-specific factor is x . Since the worker and firm seek to maximize match value as part of Nash bargaining, $M_t(x^h)$ must satisfy the following Bellman equation:

$$M_t(x^h) = \max\{z_t x^h + \beta E_t[(1 - s_t)M_{t+1}(x^h) + s_t(U_{t+1} + V_{t+1})], U_t + V_t\}.$$

Thus, match surplus may be expressed as

$$\begin{aligned} S_t(x^h) &= M_t(x^h) - U_t - V_t \\ &= \max\{z_t x^h + \beta E_t[(1 - s_t)S_{t+1}(x^h) + U_{t+1} + V_{t+1}] - U_t - V_t, 0\}. \end{aligned}$$

Substituting for U_t from (2) and setting $V_t = 0$ for all t yields

$$S_t(x^h) = \max\{z_t x^h - b + \beta(1 - s_t - A\theta_t^{1-\alpha}\pi)E_t S_{t+1}(x^h), 0\}. \quad (6)$$

Equations (4) and (6) determine free entry equilibrium paths of θ_t and $S_t(x^h)$ for given realizations of the z_t and s_t processes.

2.3 Endogenous separation

In the endogenous separation version, s_t is held constant at the value s , whereas x follows a Markov process. All new matches start at $x = x^h$, but the value of x may switch in subsequent weeks. At the end of each week t , a switch occurs with probability λ . In the latter event, the value of x for week $t + 1$ is drawn randomly according to the c.d.f. $G(x)$, taken to be lognormal with parameters μ_x and σ_x for $x < x^h$, and $G(x^h) = 1$. With probability $1 - \lambda$, x maintains its week t value into week $t + 1$.

When OJS is not allowed, match value satisfies

$$\begin{aligned} M_t(x) &= \max\{z_t x + \beta E_t[(1 - s)(\lambda \int_0^{x^h} M_{t+1}(y) dG(y) + (1 - \lambda)M_{t+1}(x)) \\ &\quad + s(U_{t+1} + V_{t+1})], U_t + V_t\}. \end{aligned}$$

Rearranging and substituting as above gives

$$S_t(x) = \max\{z_t x - b + \beta(1-s)(\lambda E_t \int_0^{x^h} S_{t+1}(y) dG(y) + (1-\lambda) E_t S_{t+1}(x)) - \beta A \theta_t^{1-\alpha} \pi E_t S_{t+1}(x^h), 0\}. \quad (7)$$

Equations (4) and (7) determine equilibrium paths of θ_t and $S_t(x)$ for given realizations of the z_t process.

2.4 OJS

The OJS version of the MP model extends the endogenous separation version by allowing matched workers to search at a cost of a . The worker search pool expands to $u_t + \phi_t$, where ϕ_t indicates the number of matched workers who search in week t . Total match formation in week t is now equal to $m(u_t + \phi_t, v_t)$. The matching probability for a searching worker, whether employed or unemployed, is $A\theta_t^{1-\alpha}$, and the probability that a vacancy contacts a worker is $A\theta_t^{-\alpha}$, where $\theta_t = v_t/(u_t + \phi_t)$.

When a matched searching worker makes a new match in week t , the worker must renounce the option of keeping his old match before bargaining with the new firm at the start of week $t+1$. As a consequence, the worker receives a payoff of $\pi S_{t+1}(x^h) + U_{t+1}$ from the new match. Since the worker's payoff from the old match cannot exceed this value, it is optimal for the worker always to accept a new match. Thus, when OJS is chosen, the match value is

$$\begin{aligned} M_t^s(x) &= z_t x - a + \beta E_t [A \theta_t^{1-\alpha} (\pi S_{t+1}(x^h) + U_{t+1} + V_{t+1}) \\ &\quad + (1 - A \theta_t^{1-\alpha}) ((1-s)(\lambda \int_0^{x^h} M_{t+1}(y) dG(y) + (1-\lambda) M_{t+1}(x)) \\ &\quad + s(U_{t+1} + V_{t+1}))], \end{aligned}$$

and the associated equilibrium match surplus is

$$\begin{aligned} S_t^s(x) &= z_t x - a - b + \beta(1 - A \theta_t^{1-\alpha})(1-s) \\ &\quad \times (\lambda E_t \int_0^{x^h} S_{t+1}(y) dG(y) + (1-\lambda) E_t S_{t+1}(x)). \end{aligned}$$

Assuming the worker's search decision is contractible, the Bellman equation for match

surplus becomes

$$\begin{aligned}
S_t(x) = & \max\{z_t x - a - b + \beta(1 - A\theta_t^{1-\alpha})(1 - s) \\
& \times (\lambda E_t \int_0^{x^h} S_{t+1}(y) dG(y) + (1 - \lambda) E_t S_{t+1}(x)), \\
& z_t x - b + \beta(1 - s)(\lambda E_t \int_0^{x^h} S_{t+1}(y) dG(y) + (1 - \lambda) E_t S_{t+1}(x)) \\
& - \beta A\theta_t^{1-\alpha} \pi E_t S_{t+1}(x^h), 0\}.
\end{aligned} \tag{8}$$

Equilibrium θ_t and $S_t(x)$ are determined by (4) and (8) in this case.

2.5 Measurement

Equilibrium worker transition rates and flows are measured as follows. A worker who is unemployed in week t becomes employed in week $t + 1$ with probability $A\theta_t^{1-\alpha}$. Thus, for all specifications the measured job finding rate and number of UE flows for week $t + 1$ are

$$JFR_{t+1} = A\theta_t^{1-\alpha}, \quad UE_{t+1} = A\theta_t^{1-\alpha} u_t.$$

Moreover, in the exogenous separation version, a worker who is employed in week t becomes unemployed in week $t + 1$ with probability s_t , giving the following measured separation rate and number of EU flows:

$$SR_{t+1} = s_t, \quad EU_{t+1} = s_t(1 - u_t).$$

Separation rates and EU flows in the endogenous separation and OJS versions depend on the distribution of x across existing matches. Let $e_t(x)$ denote the number of matches in week t having match-specific factors less than or equal to x ; note that $e_t(x^h)$ gives total employment. Since $S_t(x)$ is strictly increasing in x wherever $S_t(x) > 0$, there exists a value R_t such that $S_t(x) = 0$ if and only if $x \leq R_t$. Thus, separation occurs at the start of week $t + 1$ whenever $x \leq R_{t+1}$.⁶ In equilibrium, $e_{t+1}(x) = 0$ for $x \leq R_{t+1}$, while for $x \in (R_{t+1}, x^h)$:

$$\begin{aligned}
e_{t+1}(x) = & (1 - s)\lambda(G(x) - G(R_{t+1}))e_t(x^h) \\
& + (1 - s)(1 - \lambda)(e_t(x) - e_t(R_{t+1})).
\end{aligned}$$

⁶When $x = R_{t+1}$, the firm and worker could also choose to continue their match, as a matter of indifference. It is slightly more convenient for notational purposes to specify that separation occurs at the R_{t+1} margin.

Furthermore, for $x = x^h$:

$$e_{t+1}(x^h) = (1-s)\lambda(1-G(R_{t+1}))e_t(x^h) \\ + (1-s)(1-\lambda)(e_t(x^h) - e_t(R_{t+1})) + A\theta_t^{1-\alpha}u_t.$$

Total EU flows and the separation rate are given by

$$EU_{t+1} = (s + (1-s)\lambda G(R_{t+1}))e_t(x^h) + (1-s)(1-\lambda)e_t(R_{t+1}), \\ SR_{t+1} = \frac{EU_{t+1}}{e_t(x^h)}.$$

Finally, the implied law of motion for unemployment is

$$u_{t+1} = u_t + EU_{t+1} - UE_{t+1}.$$

In the exogenous and endogenous separation versions, vacancies are determined simply by

$$v_t = \theta_t u_t.$$

In the OJS version, ϕ_t must be known in order to determine vacancies. It can be shown that there exists a value R_t^s such that the match surplus from OJS exceeds the surplus from continuing the match with no search if and only if $x < R_t^s$. Thus, OJS is chosen whenever $R_t < R_t^s$ and $x \in (R_t, R_t^s)$. It follows that $\phi_t = e_t(R_t^s)$ and

$$v_t = \theta_t(u_t + e_t(R_t^s)).$$

3 Simulation

3.1 Calibration

Two specifications of the exogenous separation version are considered: s_t may either be constant at s , or else follow an AR(1) process given by (5) with $\sigma_s > 0$. Combined with the endogenous separation and OJS versions, this gives four specifications to calibrate. Parameter choices for the four cases are given in columns two through four of Table 1 (columns five and six are discussed in Section 6).

The parameters b , α and π are set to the standard values discussed by Mortensen and Nagypál (2007a). Calibration of c draws on survey evidence on employer recruitment behavior. Results cited in Barron, et al. (1997) point to an average vacancy duration of roughly three weeks. Moreover, Barron and Bishop's (1985) data show an average of

about nine applicants for each vacancy filled, with two hours of work time required to process each application. These figures suggest an average investment of 20 hours per vacancy filled, or 6.7 hours per week the vacancy is posted. This amounts to 17 percent of a 40 hour work week; thus, it is reasonable to assign this value to c , given that weekly productivity is normalized to unity.

For the endogenous separation and OJS specifications, λ is chosen to yield a mean waiting time of three months between switches of the match-specific productivity factor. To ensure comparability across specifications, x^h is adjusted to generate mean match productivity of unity in all cases. The parameter a in the OJS specification is chosen so that the mean monthly job-to-job transition rate in the simulated data matches the value of 3.2 percent calculated by Moscarini and Thomsson (2007) using CPS data.

To select the parameters ρ_z and σ_z , paths of z_t are simulated using (1) and converted to monthly averages. ρ_z and σ_z are determined in order to match the productivity process estimated from the simulated data to the process used by Fujita and Ramey (2007). The latter process is based on monthly estimates that control for the possibility of endogenous feedbacks to productivity. The value of the weekly discount factor β is consistent with an annual interest rate of four percent.

Selection of the remaining parameters relies on monthly job finding and separation rate data from Fujita and Ramey (2006). These data derive from the CPS for the 1976-2005 period, and are adjusted for margin error and time aggregation error. In all cases, the parameters A and s are chosen to ensure that the simulated data generate mean monthly job finding and separation rates of 34 percent and two percent, respectively, consistent with the Fujita-Ramey evidence.

In the AR(1) specification, ρ_s and σ_s are chosen to match the standard deviation and first-order autocorrelation of the simulated separation rate series, aggregated to quarterly and HP filtered (with smoothing parameter 1600), to the empirical values of these moments in the Fujita-Ramey data. This procedure is justified under the hypothesis that all variability in the separation rate is exogenous. Finally, the parameter μ_x is set to zero in the endogenous separation and OJS specifications, and σ_x is adjusted to match the standard deviation of the simulated quarterly separation rate series, HP filtered, with its empirical value.

3.2 Solution method

The model consists of the free entry condition (4), the surplus equation (6), (7) or (8), and the driving processes (1) and (5). To solve the model, let the stochastic elements be represented on grids. The method of Tauchen (1986) is used to represent the processes z_t and s_t as Markov chains having state spaces $\{z_1, \dots, z_I\}$ and $\{s_1, \dots, s_K\}$ and transition matrices $\Delta^z = [\delta_{ij}^z]$ and $\Delta^s = [\delta_{kl}^s]$, where $\delta_{ij}^z = \text{Prob}\{z_{t+1} = z_j | z_t = z_i\}$ and $\delta_{kl}^s = \text{Prob}\{s_{t+1} = s_l | s_t = s_k\}$. $G(x)$ is approximated by a discrete distribution with support $\{x_1, \dots, x_M\}$, satisfying $x_1 = 1/M$, $x_m - x_{m-1} = x^h/M$ and $x_M = x^h$. The associated probabilities $\{\gamma_1, \dots, \gamma_M\}$ are $\gamma_m = g(x_m)/M$ for $m = 1, \dots, M-1$, where $g(x)$ is the lognormal density, and $\gamma_M = 1 - \gamma_1 - \dots - \gamma_{M-1}$.

Market tightness and match surplus may be represented as

$$\theta_t = \theta(z_i, s_k), \quad S_t(x_m) = S(z_i, s_k, x_m),$$

where z_i and s_k are the aggregate states prevailing in period t . Equations (4), (6) and (7) take the forms, for $i = 1, \dots, I$, $k = 1, \dots, K$, $m = 1, \dots, M$:

$$\beta A \theta(z_i, s_k)^{-\alpha} (1 - \pi) \sum_{j,l} \delta_{ij}^z \delta_{kl}^s S(z_j, s_l, x^h) = c, \quad (9)$$

$$\begin{aligned} S(z_i, s_k, x^h) = & \max\{z_i x^h - b \\ & + \beta(1 - s_k - \beta A \theta(z_i, s_k)^{1-\alpha} \pi) \sum_{j,l} \delta_{ij}^z \delta_{kl}^s S(z_j, s_l, x^h), 0\}, \end{aligned} \quad (10)$$

$$\begin{aligned} S(z_i, s_k, x_m) = & \max\{z_i x_m - b + \beta(1 - s_k) \lambda \sum_{j,l,n} \delta_{ij}^z \delta_{kl}^s \gamma_n S(z_j, s_l, x_n) \\ & + \beta(1 - s_k)(1 - \lambda) \sum_{j,l} \delta_{ij}^z \delta_{kl}^s S(z_j, s_l, x_m) \\ & - \beta A \theta(z_i, s_k)^{1-\alpha} \pi \sum_{j,l} \delta_{ij}^z \delta_{kl}^s S(z_j, s_l, x^h), 0\}, \end{aligned}$$

and similarly for (8).

Numerical solutions are obtained via backward substitution. For example, let $\theta^T(z_i, s_k)$ and $S^T(z_i, s_k, x^h)$ be the functions obtained after T iterations of (9) and (10). At iteration $T+1$, these functions are updated to

$$\begin{aligned} S^{T+1}(z_i, s_k, x^h) = & \max\{z_i x^h - b \\ & + \beta(1 - s_k - \beta A \theta^T(z_i, s_k)^{1-\alpha} \pi) \sum_{j,l} \delta_{ij}^z \delta_{kl}^s S^T(z_j, s_l, x^h), \end{aligned}$$

$$\theta^{T+1}(z_i, s_k) = \left(\frac{\beta A(1 - \pi)}{c} \sum_{j,l} \delta_{ij}^z \delta_{kl}^s S^{T+1}(z_j, s_l, x^h) \right)^{\frac{1}{\alpha}}.$$

Convergence follows as a consequence of the saddlepoint stability property of the matching model, which makes for stability in the backward dynamics.⁷

3.3 Evaluation procedure

The empirical data series used for purposes of model evaluation are constructed as follows. Employment, unemployment, job finding and separation rates, and UE and EU flows are quarterly averages of the monthly series from Fujita and Ramey (2006), covering 1976Q2-2005Q4. The productivity series is obtained by dividing quarterly GDP by the employment series. Vacancies are measured as quarterly averages of the Conference Board’s monthly Help Wanted Index. All quarterly series are logged and HP filtered, with a smoothing parameter of 1600.

To conform with the empirical series, the simulated weekly data are averaged to quarterly frequency, logged and HP filtered using smoothing parameter 1600. Each simulated quarterly series consists of 619 observations, of which the last 119 are used to calculate the reported statistics. For each of the four specifications, 1000 replications are run, and averages of the statistics across the replications are presented in the figures.

4 Results

4.1 Unemployment and worker transition rates

Panel A of Figure 1 compares the empirical standard deviations of unemployment and worker transition rates with the values obtained from the four specifications of the MP model. The empirical standard deviation of unemployment, equalling 9.5 percent, is over eight times greater than the value of roughly 1.2 percent generated by the constant separation rate specification. This conforms to the observation of Costain and Reiter (2006) and Shimer (2005) that the MP model with a constant separation rate produces far too little unemployment volatility.

However, the empirical separation rate is not in fact constant, as it has a standard deviation of 5.8 percent. The other three versions of the MP model, which allow for

⁷In solving the model, $I = K = 13$ and $M = 200$ are chosen. The tolerance for pointwise convergence of $\theta(z_i, s_k)$ and $S(z_i, s_k, x_m)$ is 10^{-8} .

fluctuations in the separation rate, are calibrated to match the latter standard deviation. All three specifications yield significantly greater unemployment volatility. The standard deviation of unemployment in the OJS specification, in particular, is 6.2 percent, or over 60 percent of its empirical value. Thus, incorporating variability at the separation margin, under any of the three specifications, greatly enhances the ability of the MP model to produce realistic unemployment volatility.

At the same time, all four specifications of the MP model yield highly unrealistic volatility of the job finding rate, with the empirical standard deviation being nearly six times the simulated value in each specification. Improving the model's performance at the separation margin does not mitigate its problems at the job finding margin.

Panel B of Figure 1 presents contemporaneous correlations with productivity. The constant, endogenous and OJS specifications each produce strong negative comovement between unemployment and productivity, in line with the data, while the AR(1) specification generates little comovement. All four specifications give rise to strong positive productivity comovement for the job finding rate. The two exogenous separation specifications, however, fail to replicate the negative correlation between productivity and the separation rate that is a robust feature of the data. The two endogenous separation rate specifications succeed in capturing this negative correlation.

Elasticities of the variables with respect to productivity are shown in Panel C.⁸ The productivity elasticities offer somewhat cleaner measures of comovement, insofar as they reflect the effects of variations in productivity in isolation from other disturbances; see Mortensen and Nagypál (2007a). The elasticities may also be interpreted as rough measures of responsiveness to productivity shocks. For unemployment, the empirical productivity elasticity of -6.5 is over six times greater in magnitude than the elasticities produced by the two exogenous separation specifications. However, each of the endogenous separation specifications achieves a close match with the empirical elasticity; the value for the OJS model, in particular, stands at -6.2.

Findings are similar for the separation rate elasticities, where the exogenous separation specifications provide highly unrealistic values, while those of the endogenous separation specifications are empirically reasonable. Across all four specifications, however, the productivity elasticities of the job finding rate are far too low: the empirical value is 4.0, while the simulated values do not exceed 1.4.

⁸These productivity elasticities are computed as follows. Let p_t denote productivity in quarter t , and let y_t be any series. Then the productivity elasticity is $Corr(p_t, y_t)SD(y_t)/SD(p_t)$.

In summary, introducing variability at the separation margin greatly magnifies the degree of unemployment volatility generated by the MP model, whether the separation rate is determined exogenously or endogenously. Moreover, when the separation rate is endogenous, the model generates realistic responsiveness of unemployment and the separation rate to productivity shocks, whereas the exogenous separation versions yield little or no responsiveness. For all of the specifications considered, the simulated job finding rate is deficient in both its volatility and its responsiveness to productivity.

4.2 Worker flows

Figure 2 considers gross flows of workers between unemployment and employment. As Panel A indicates, the constant separation rate specification produces almost no volatility in UE and EU flows. This is contrary to the data, where the standard deviations for both flows are roughly half of the standard deviation of unemployment. The three specifications with variable separation rates, in contrast, do a good job in matching the empirical standard deviations of both UE and EU flows. Thus, variability at the separation margin is crucial for producing realistic variability in worker flows.

Panel B shows that with constant separation rates, worker flows exhibit a strong positive correlation with productivity. This contradicts the substantial negative correlation seen in the data. In the constant separation rate model, worker flows are driven principally by procyclical movements in the job finding rate, allowing little scope for explaining their observed countercyclical movements. The AR(1) model, in turn, yields essentially acyclical movements in worker flows, reflecting the fact that exogenous separation rate shocks are uncorrelated with the productivity process.

The two endogenous separation rate specifications, on the other hand, produce strong negative correlations between productivity and worker flows. Panel C indicates that worker flows are almost entirely unresponsive to productivity in the two exogenous separation rate specifications, whereas they exhibit strong negative responses in the two endogenous separation specifications.

4.3 Vacancies and market tightness

Vacancies and market tightness are considered in Figure 3. Panel A shows that all four specifications produce insufficient volatility of both vacancies and market tightness, consistent with the low volatility of the job finding rate observed in Figure 1. The standard

deviation of market tightness in the OJS model is significantly greater than in the other specifications, however. This occurs because empirical market tightness is measured as vacancies divided by unemployment, whereas in the theoretical model the variable θ_t also includes employed searching workers in its denominator. Thus, the empirical measure omits procyclical movements in the number of employed searchers that offset countercyclical movements in unemployment, leading to greater variability of the empirical ratio.

Panel B depicts the productivity correlations. Both versions of the exogenous separation model replicate the procyclical movements of vacancies seen in the data, whereas the endogenous separation model without OJS yields countercyclical movements. The latter finding reflects conflicting effects on the incentive to post vacancies. Following a negative productivity shock, the returns to forming a new match are relatively low, reducing vacancy posting incentives. This effect drives vacancies downward in the constant and AR(1) models. In the endogenous separation model without OJS, however, the separation rate rises in response to the productivity shock, pushing up the number of unemployed workers. This raises the vacancy matching probability and enhances the incentive to post vacancies. On balance, the latter effect dominates, and vacancies become negatively correlated with productivity.

The OJS model, however, produces a strong positive correlation between vacancies and productivity, despite the fact that the separation rate is determined endogenously. With OJS, a negative productivity shock induces a fall in the number of employed searchers which partially offsets the rise in unemployment. Thus, endogenous separation is consistent with realistic vacancy comovement once OJS is incorporated. Note finally that all four specifications yield positive productivity comovement for market tightness, in line with the data.

Productivity elasticities are shown in Panel C. The empirical productivity elasticity of vacancies far exceeds the elasticities obtained from the three specifications without OJS. In the OJS specification, however, the elasticity of vacancies amounts to over half of its empirical value. Thus, incorporating OJS greatly improves the ability of the model to match the productivity responsiveness of vacancies. For market tightness, the OJS model performs even better, as the simulated productivity elasticity amounts to nearly 75 percent of its empirical value. Thus, while variability and productivity responsiveness are insufficient for all four specifications of the MP model, the OJS version significantly improves on the others. The superior performance of the OJS specification results from procyclical variations in the number of searching workers, which make vacancies more

responsive to productivity at given levels of market tightness.

4.4 Beveridge correlation

Panel A of Figure 4 presents contemporaneous correlations between unemployment and vacancies, capturing the Beveridge curve relationship. The value of -0.95 observed in the data is reasonably well matched by the value -0.76 generated by the constant separation rate specification. The AR(1) specification, in contrast, produces a highly counterfactual value of 0.75, and for the endogenous separation specification the value is an even more unrealistic 0.92. In the AR(1) model, a small positive separation rate shock induces a large inflow into unemployment, because the stock of employed workers is relatively large. Workers become easier to find, while productivity is unchanged, so incentives to post vacancies rise. A related effect operates in the endogenous separation model, where a negative productivity shock drives up unemployment, making workers easier to find and raising the incentive to post vacancies.

For the OJS model, the unemployment-vacancy correlation amounts to -0.96, essentially indistinguishable from the empirical value. Here, procyclical movements in the number of employed searchers lead to procyclical changes in vacancy posting incentives, giving rise to a realistic Beveridge correlation.

4.5 Transition rate comovement

Contemporaneous correlations between job finding and separation rates are depicted in panel B of Figure 4. In the data, these rates have a negative correlation of about -0.5, whereas the correlations are essentially zero in the two exogenous separation specifications. The two endogenous separation specifications, on the other hand, produce strong negative correlations, on the order of -0.88. The latter specifications achieve the correct transition rate comovement chiefly because the two rates themselves respond realistically to the common underlying productivity process.

5 Dynamic interrelationships

5.1 Cross productivity elasticities

Figures 5 through 7 present elasticities with productivity at various leads and lags. To focus the discussion, only the constant and OJS specifications are considered; findings are

qualitatively similar for the other specifications.

Panel A of Figure 5 shows the elasticities of unemployment with respect to productivity at each of the given lags; e.g., the reported elasticity at a lag of 2 represents the correlation between current unemployment and productivity lagged by two quarters, multiplied and divided by the appropriate standard deviations. Empirically, the responsiveness of unemployment to productivity achieves its peak of -8 at a lag of two quarters, meaning that productivity leads unemployment. For the OJS model, the peak of just under -6 is reached at a zero to one quarter lag. Thus, the model fails to produce realistic response dynamics, in that unemployment responses occur more quickly than in the data. A similar finding can be observed for the constant separation rate model.

Cross productivity elasticities for the job finding rate are given in panel B. The empirical job finding rate responds more slowly than does unemployment, with the peak elasticity occurring at a lag of three quarters. For both specifications of the MP model, in contrast, the elasticities peak sharply at zero lag. Thus, while the actual productivity responses of the job finding rate are spread out across time, they occur more or less contemporaneously with productivity in the MP model. Cross elasticities for vacancies and market tightness, shown in Figure 7, display similar properties. As stressed by Fujita and Ramey (2007), the fact that vacancies can jump instantaneously in the MP model causes market tightness to respond too quickly to productivity shocks. This undermines the model's ability to generate realistic dynamic responses of unemployment, the job finding rate, vacancies and market tightness.

Panel C of Figure 5 depicts the cross elasticities for the separation rate, while the cross elasticities for UE and EU flows are given in Figure 6. In these instances, the OJS model does a reasonable job of matching the empirical response pattern: the separation rate and EU flows adjust contemporaneously with productivity or lead it slightly, while UE flows lag productivity by about a quarter. In the constant separation rate model, in contrast, these variables are essentially unresponsive to productivity at all leads and lags.

In summary, the MP model with endogenous separation yields sensible dynamics of the separation rate and worker flows, whereas the responses of unemployment, the job finding rate, vacancies and market tightness are insufficiently sluggish. In no case does the model with exogenous separation deliver a realistic pattern of responses.

5.2 Beveridge correlations

Cross correlations between unemployment and vacancies are given in panel A of Figure 8. While both the constant and OJS specifications provide strong negative Beveridge correlations, in the constant separation rate model the peak correlation is achieved at a lead of one quarter, i.e., vacancies lead unemployment by one quarter, whereas in the data the peak occurs at zero lag. This reflects the mechanics of the model, wherein changes in unemployment are driven by changes in the job finding rate, which themselves are tied to fluctuations in vacancies. The OJS model, on the other hand, exhibits its peak correlation at zero lag, and matches fairly well the dynamic pattern seen in the data.

5.3 Transition rate correlations

Panel B of Figure 8 reports the cross correlations of job finding and separation rates. In the data, strong negative correlations are achieved at lags of -1 to -4 quarters, meaning that the separation rate leads the job finding rate. While the correlations for the OJS model exhibit a slight negative phase shift, they fail to capture adequately the overall dynamic pattern. Of course, all of these correlations are zero in the constant separation rate model.

6 Hagedorn-Manovskii calibration

6.1 Calibration strategy

Hagedorn and Manovskii (2008, henceforth HM) propose an alternative approach to calibrating the MP model that draws on wage and profit data. In all four specifications of the MP model, the wage rate determined by Nash bargaining is

$$w_t(x) = (1 - \pi)b + \pi(z_t x + \theta_t c),$$

where x is identically equal to x^h in the exogenous separation specifications. HM point out that under standard calibrations, the empirical productivity elasticity of wages is much lower than the elasticity generated by the model. They propose an alternative calibration strategy that aims to match this elasticity, along with the empirical relationship between mean wage and profit levels.

To assess the implications of the HM calibration, this paper follows Hornstein, et al. (2005) in varying the calibrated values of b and π in order to match the productivity

elasticity of wages and the steady state wage-productivity ratio to the values 0.5 and 0.97, respectively. For brevity, only the constant and OJS specifications are considered.

The new calibrations are reported in columns five and six of Table 1. As noted by Hornstein, et al., matching the empirical statistics requires large increases in the b parameter and large decreases in the π parameter. For the constant separation rate model, the A parameter is adjusted to match the mean job finding rate, while for the OJS model the parameters x^h , s and σ_x are also adjusted to normalize mean productivity and match the mean and standard deviation of the separation rate. Importantly, under the HM calibration the volume of job-to-job transitions is essentially zero, even when the search cost parameter a is set to zero; the latter value is adopted here.⁹ The model is solved and simulated according to the procedures discussed earlier.

6.2 Results

Results are presented in Figures 9 through 12, which parallel Figures 1 through 4 in their content. Statistics pertaining to the standard calibrations of the constant and OJS specifications, taken from the earlier figures, are depicted alongside statistics obtained from the corresponding HM calibrations. Panel A of Figure 9 demonstrates that the HM calibration produces much more realistic volatility of unemployment and the job finding rate for both the constant and OJS specifications. Moreover, the job finding rate becomes highly responsive to productivity, as seen in panel C. The responsiveness of the separation rate in the OJS model declines considerably, however. This reflects the fact that, following a negative productivity shock, strong downward movement in the job finding rate reduces separation incentives by worsening workers' outside option.

Figure 10 reveals that the HM calibration enhances the volatility of UE flows in the constant separation rate model, but it does not appreciably raise the volatility of EU flows, nor does it mitigate the counterfactual procyclicality of worker flows implied by this specification. Moreover, worker flows become less responsive to productivity in the OJS model. For UE flows, in particular, strong procyclical movements in the job finding rate serve to neutralize the countercyclical movements in the separation rate, leaving virtually no responsiveness to productivity.

⁹In particular, $R_t < R_t^s$ occurs only for the productivity states z_i for $i = 1, 2, 3$; moreover, in these states the interval (R_t, R_t^s) is much smaller than the grid size $x_m - x_{m-1}$. Thus, while OJS is positive, it is approximated as zero in the simulation. See Section 6.3 for further discussion.

The HM calibration greatly improves the performance of both specifications in matching the empirical features of vacancies and market tightness, as Figure 11 demonstrates. Finally, the Beveridge and transition rate correlations are presented in Figure 12. These are essentially unaffected for the constant separation rate model, while they become somewhat smaller in magnitude for the OJS model. Although fluctuations in the number of employed searchers play only a negligible role in this case, the correct Beveridge correlation emerges because vacancies become much more responsive to productivity fluctuations.

6.3 HM calibration and OJS

Incentives for OJS are linked to the size of the worker's bargaining weight. Using (8), the net gain in match surplus from searching versus not searching may be expressed as

$$\begin{aligned} \text{Net gain from OJS} &= -a + A\theta_t^{1-\alpha}\beta E_t\pi S_{t+1}(x^h) \\ &\quad - A\theta_t^{1-\alpha}(1-s)\beta E_t(\lambda \int_0^{x^h} S_{t+1}(y)dG(y) + (1-\lambda)S_{t+1}(x)) \end{aligned}$$

Observe that the benefit of OJS derives from the prospect of starting a new match at the highest level of surplus, $S_{t+1}(x^h)$. The current worker-firm match obtains only proportion π of this surplus, however. Thus, at very low values of π , such as that associated with the HM calibration, worker-firm matches receive a very small share of the surplus from new matches, so incentives for OJS are low.

7 Conclusion

This paper considers four specifications of the standard MP model that differ in how they treat the separation margin. The specifications are calibrated at weekly frequency and solved using a nonlinear method. Allowing for realistic time variation of the separation rate greatly increases the volatility of unemployment in the simulated data. In the specification with OJS, for example, the standard deviation of unemployment equals 60 percent of its empirical value. Thus, moving beyond constant separation rates goes a long way towards redressing the problem of insufficient unemployment volatility in the MP model.

Both of the specifications with exogenous separation rates fail to reproduce the empirical volatility and productivity responsiveness of the separation rate and worker flows. The endogenous separation specifications, in contrast, yield empirically reasonable behavior along these dimensions, and the specification with OJS also generates a realistic

Beveridge curve correlation. Furthermore, the endogenous separation specifications imply more realistic dynamic interrelationships in comparison to the exogenous separation ones.

Two broad conclusions emerge from this analysis. First, the endogenous separation specification with OJS dominates both of the exogenous separation specifications along all dimensions considered. From the empirical standpoint, there seems to be no justification for assuming exogenous separation when modelling the separation margin.

Second, the OJS version of the MP model, as articulated in Pissarides (2000), does a remarkable job in matching labor market facts even under the standard calibration, although the model still generates insufficient volatility of the job finding rate and related variables. Adopting the HM calibration largely resolves the latter failings, but it fails to generate a realistic volume of job-to-job transitions.

The inability of the MP model to generate sluggish dynamics suggests that it does not deal adequately with key structural features of the labor market. Fujita and Ramey (2007) argue that fixed costs of vacancy creation may be salient in practice, and they show that introducing these costs into the MP model with constant separation rates leads to substantial improvements in its dynamic performance. Further investigations in this direction might lead to a more complete resolution of this issue.

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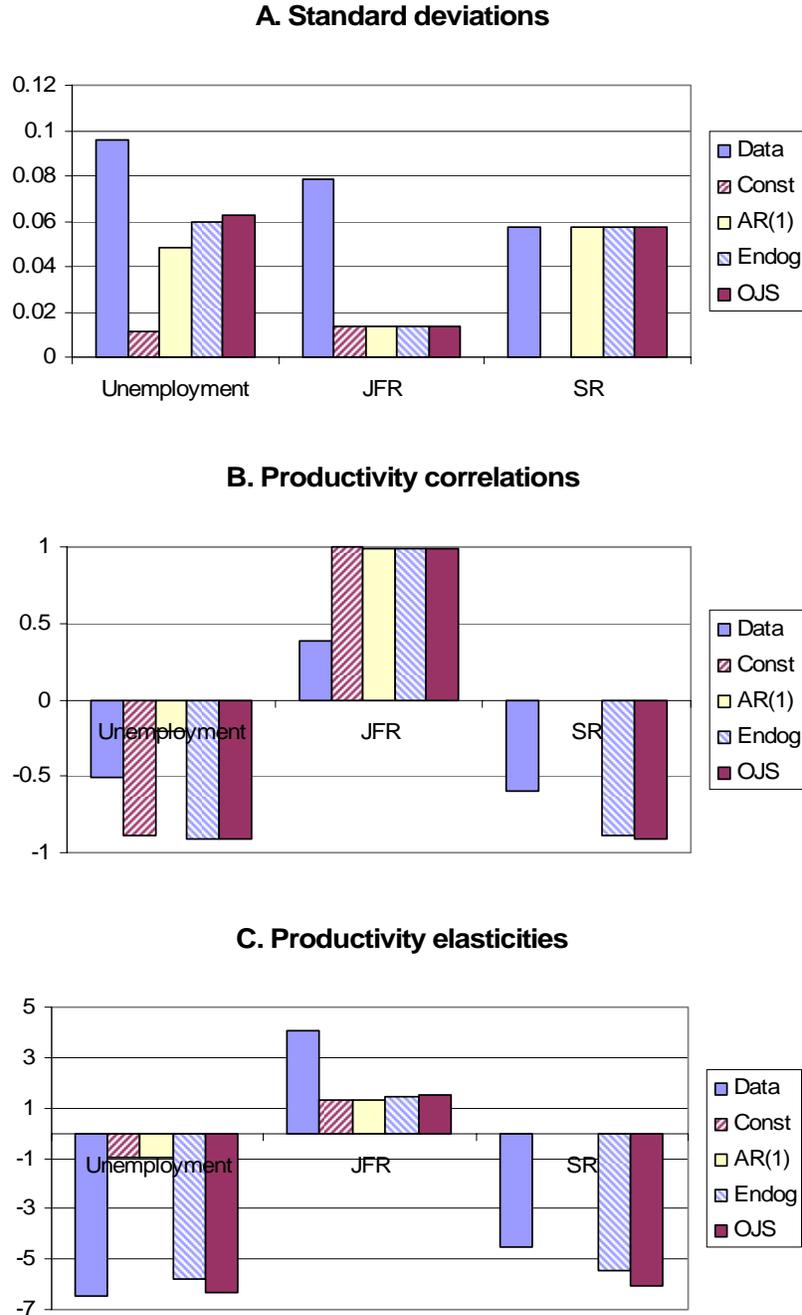
Table 1 Parameter values

<u>Parameter</u>	<u>Const</u>	<u>AR(1)</u>	<u>Endog</u>	<u>OJS</u>	<u>Const-HM</u>	<u>OJS-HM</u>
b	0.7	0.7	0.7	0.7	0.955	0.934
c	0.17	0.17	0.17	0.17	0.17	0.17
a	-	-	-	0.163	-	0
A	0.083	0.083	0.081	0.0835	0.068	0.056
α	0.6	0.6	0.6	0.6	0.6	0.6
π	0.6	0.6	0.6	0.6	0.07	0.062
x^h	1.00	1.00	1.17	1.15	1.00	1.13
s	0.005	0.005	0.0015	0.004	0.005	0.0048
ρ_s	0	0.97	-	-	-	-
σ_s	0	0.0168	-	-	-	-
λ	-	-	0.085	0.085	-	0.085
μ_x	-	-	0	0	-	0
σ_x	-	-	0.2275	0.2354	-	0.1426
ρ_z	0.99	0.99	0.99	0.99	0.99	0.99
σ_z	0.0027	0.0027	0.0027	0.0027	0.0027	0.0027
β	0.9992	0.9992	0.9992	0.9992	0.9992	0.9992

Parameters: b : unemployment payoff. c : vacancy posting cost. a : OTJ search cost. A, α : parameters of matching function. π : worker bargaining weight. x^h : highest value of match-specific productivity factor. s : mean exogenous separation probability. ρ_s, σ_s : parameters of exogenous separation process. λ, μ_x, σ_x : parameters of match-specific productivity process. ρ_z, σ_z : parameters of aggregate productivity process. β : discount factor. See text for explanation of calibration procedure.

Specifications: Const: constant separation rate model. AR(1): AR(1) separation rate model. Endog: endogenous separation rate model without OJS. OJS: endogenous separation rate model with OJS. Const-HM: constant separation rate model, Hagedorn-Manovskii calibration. OJS-HM: endogenous separation rate model with OJS, Hagedorn-Manovskii calibration.

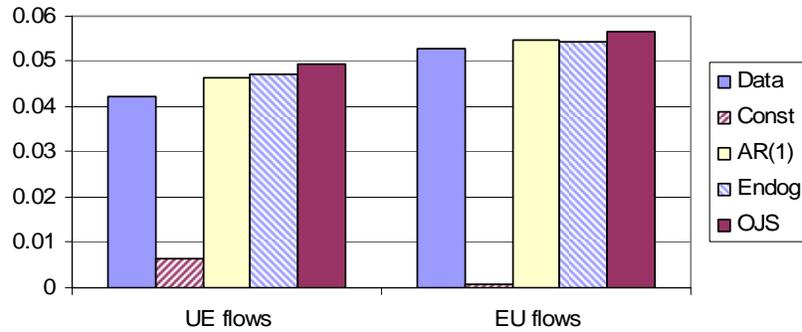
Figure 1. Unemployment and worker transition rates



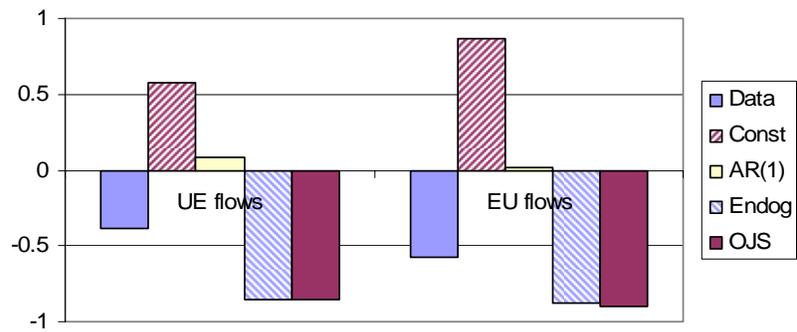
Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. AR(1): AR(1) separation rate model. Endog: endogenous separation rate model without OJS. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 2. Worker flows

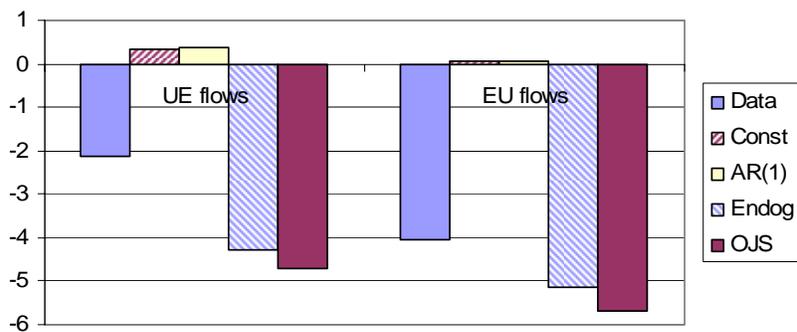
A. Standard deviations



B. Productivity correlations

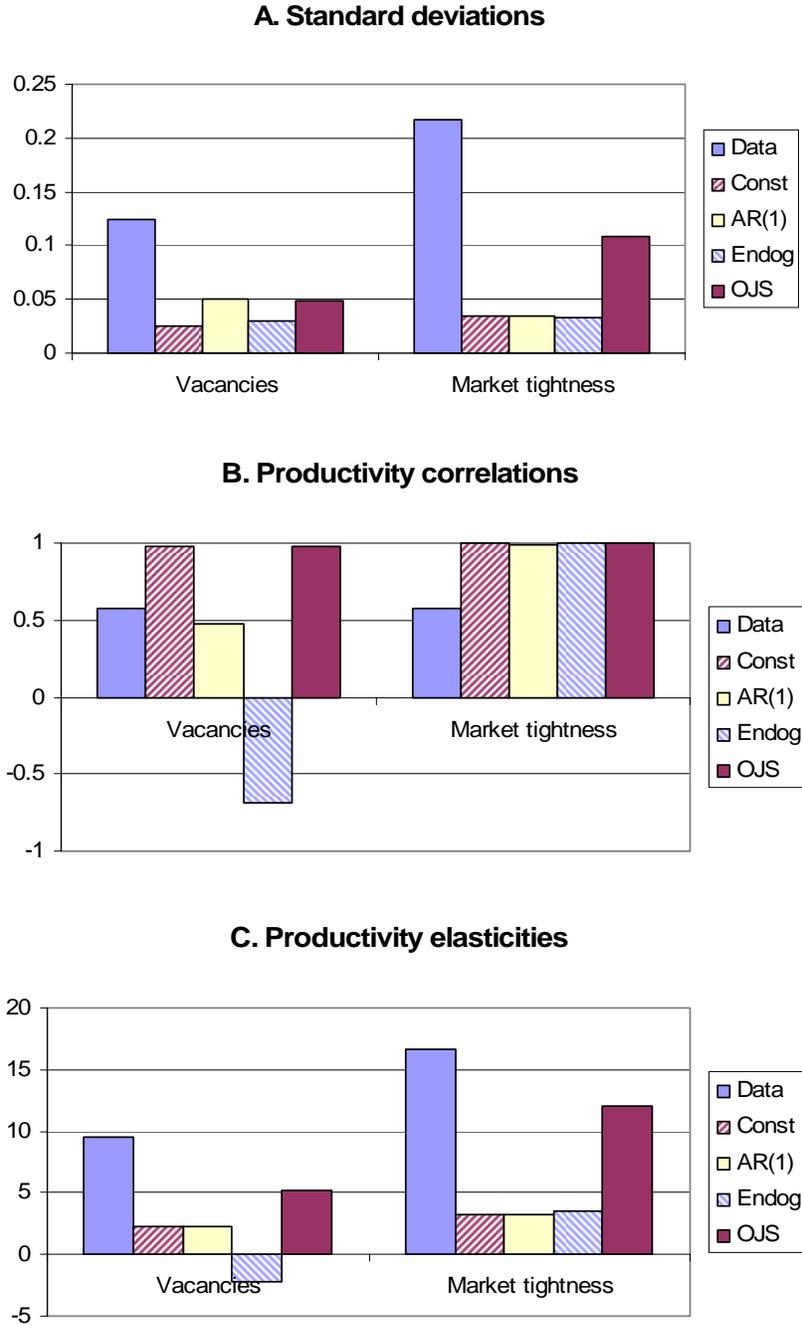


C. Productivity elasticities



Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. AR(1): AR(1) separation rate model. Endog: endogenous separation rate model without OJS. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 3. Vacancies and market tightness



Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. AR(1): AR(1) separation rate model. Endog: endogenous separation rate model without OJS. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

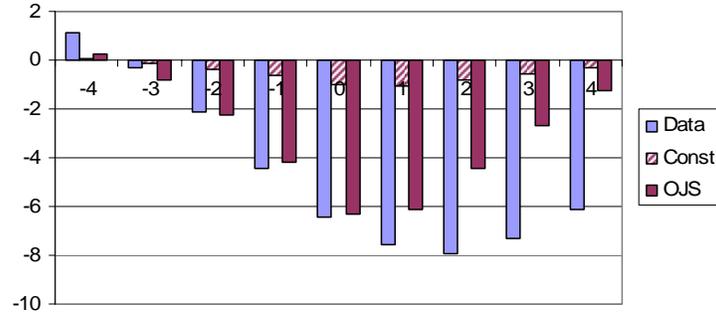
Figure 4. Contemporaneous correlations



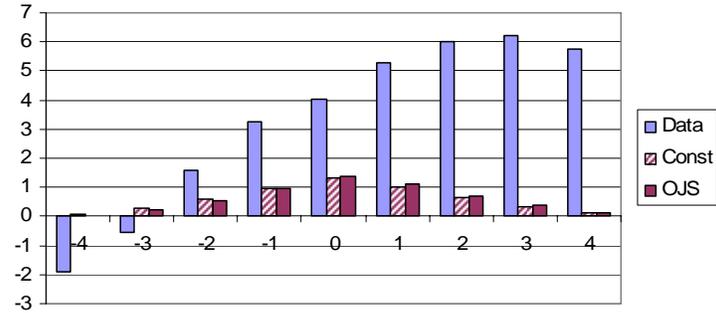
Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. AR(1): AR(1) separation rate model. Endog: endogenous separation rate model without OJS. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 5. Cross productivity elasticities:
Unemployment and worker transition rates

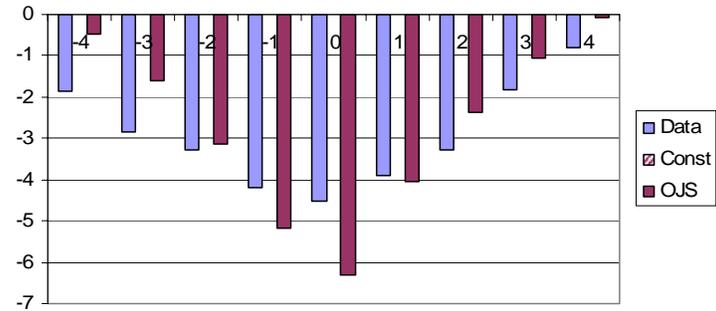
A. Unemployment



B. Job finding rate

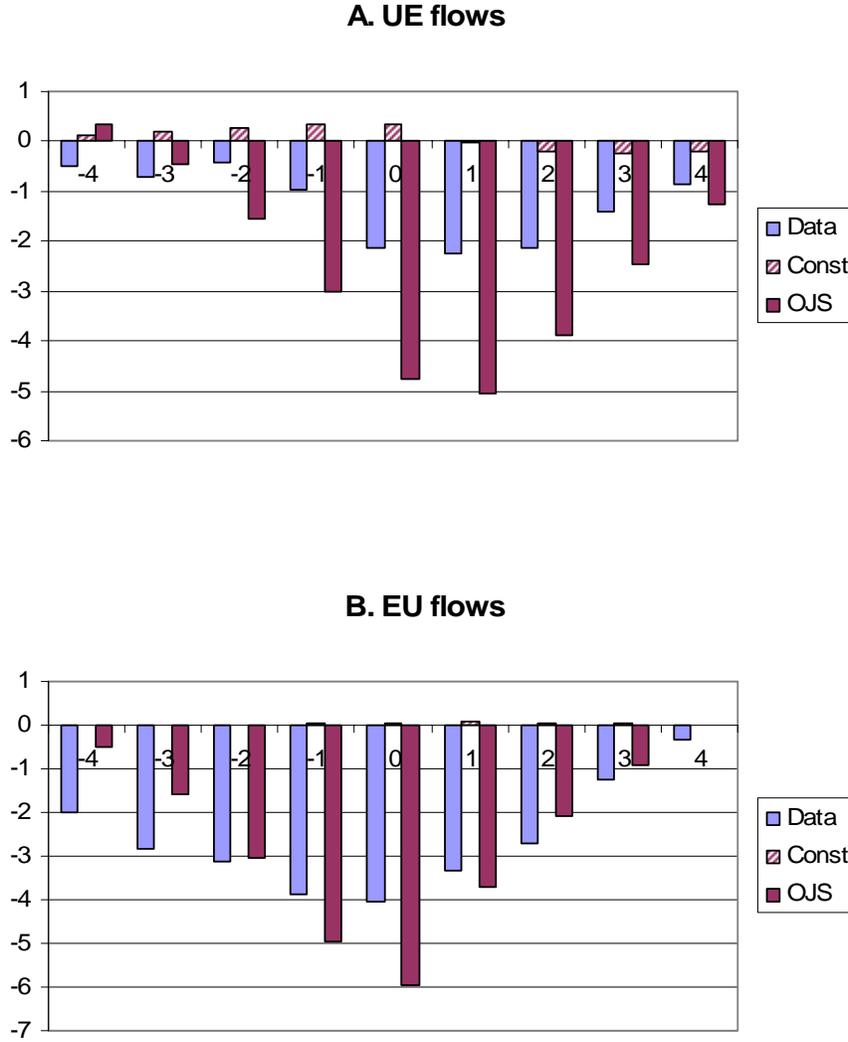


C. Separation rate



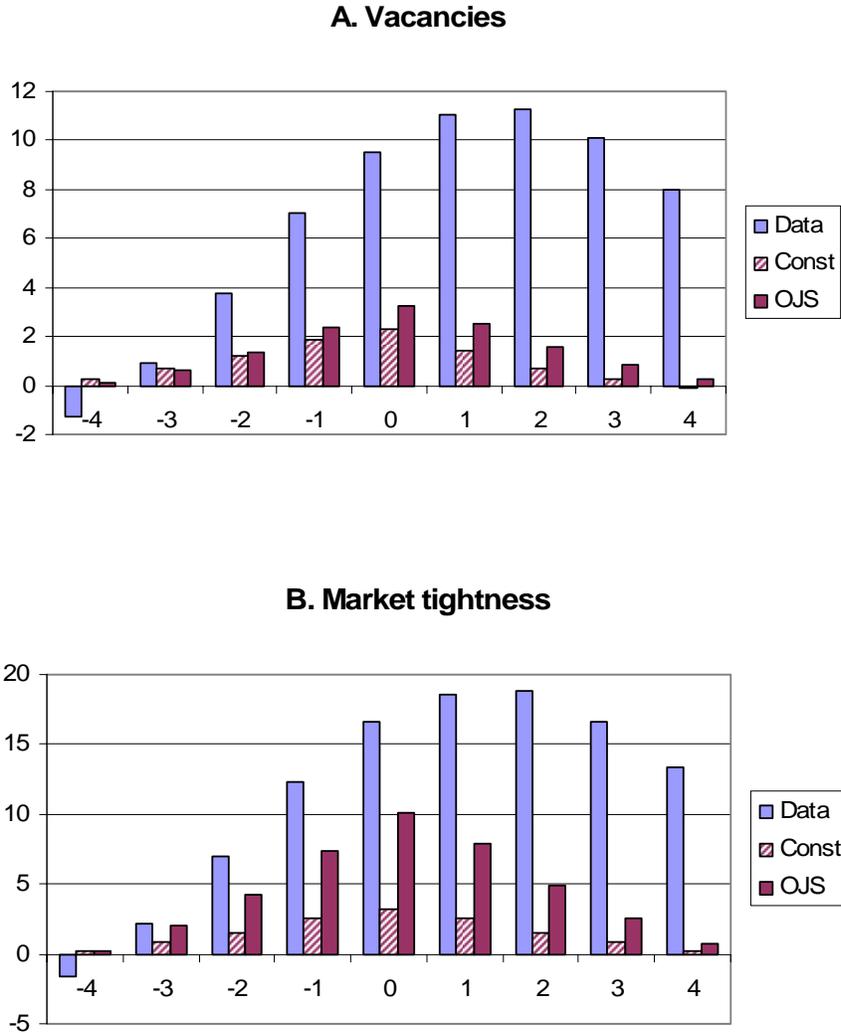
Notes: Graphs show correlations between variables at t and productivity at $t-i$, where $i =$ abscissa. Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 6. Cross productivity elasticities:
Worker flows



Notes: Graphs show correlations between variables at t and productivity at $t-i$, where $i =$ abscissa. Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

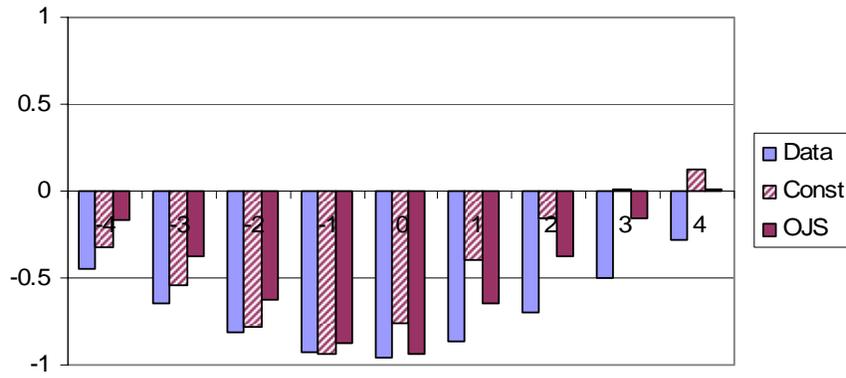
Figure 7. Cross productivity elasticities:
Vacancies and market tightness



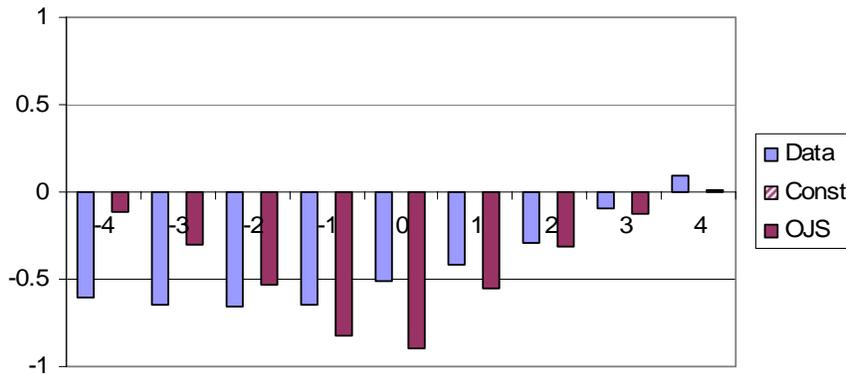
Notes: Graphs show correlations between variables at t and productivity at $t-i$, where $i =$ abscissa. Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. OJS: endogenous separation rate model with OJS. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 8. Cross correlations

A. Unemployment and vacancies



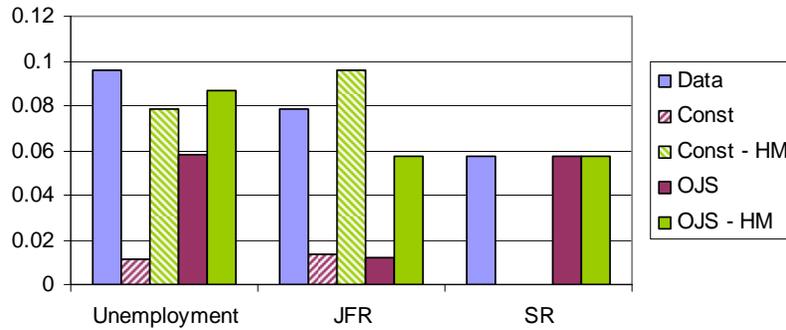
B. Job finding and separation rates



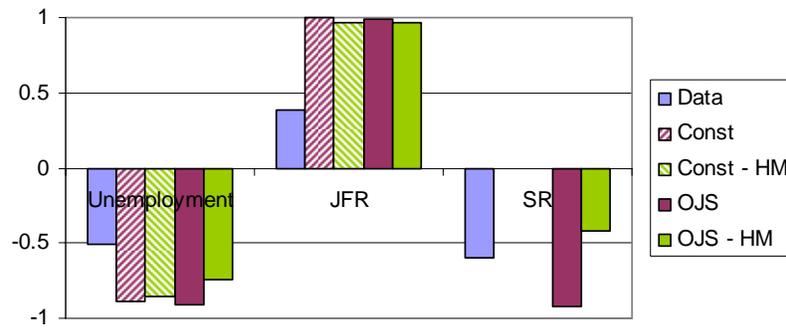
Notes: Panel A: correlations between vacancies at t and unemployment at $t-i$, where $i =$ abscissa. Panel B: correlations between separation rate at t and job finding rate rate at $t-i$. Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. AR(1): AR(1) separation rate model. Endog: endogenous separation rate model without OJS. OJS: endogenous separation rate model with OJS. See Table 1 for calibration. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 9. Unemployment and worker transition rates:
Standard and HM calibrations

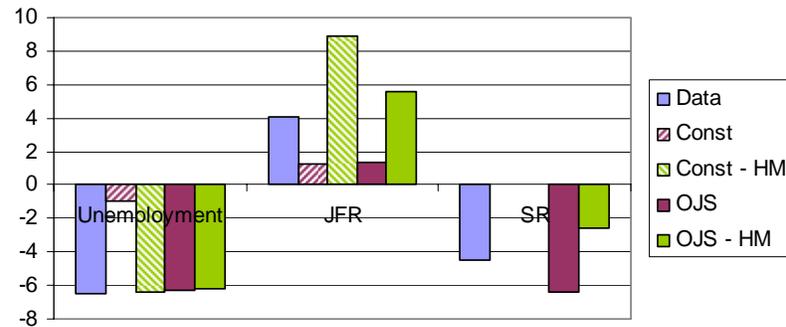
A. Standard deviations



B. Productivity correlations



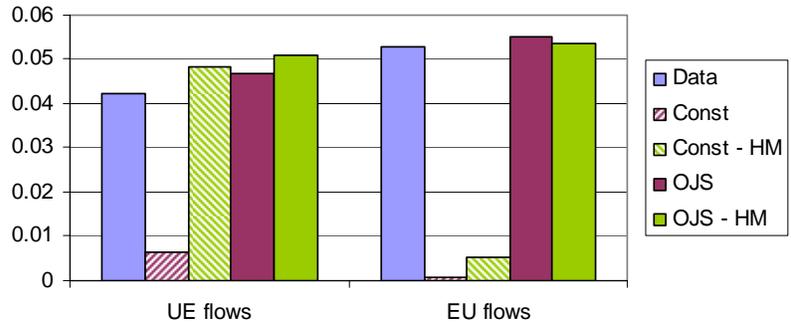
C. Productivity elasticities



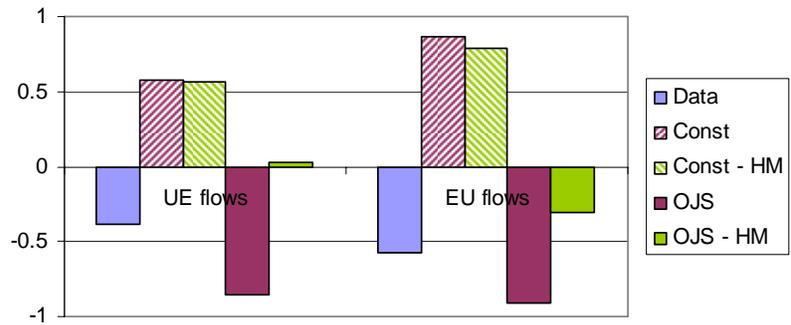
Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. Const-HM: constant separation rate model, HM calibration. OJS: endogenous separation rate model with OJS. OJS-HM: endogenous separation rate model with OJS, HM calibration. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 10. Worker flows:
Standard and HM calibrations

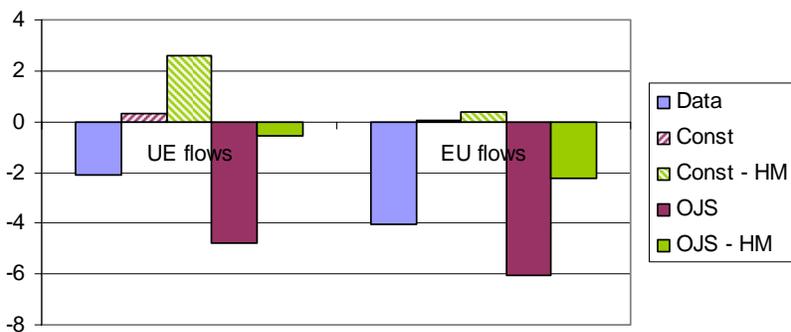
A. Standard deviations



B. Productivity correlations

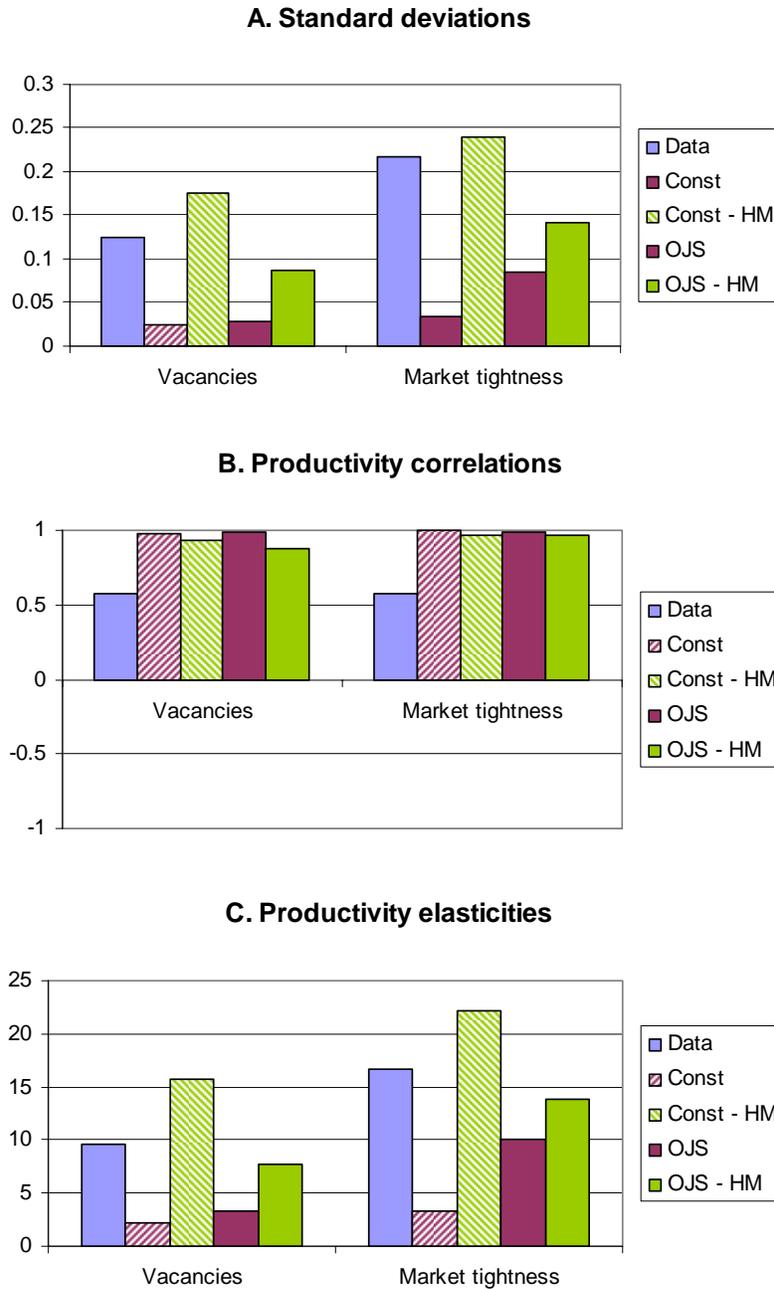


C. Productivity elasticities



Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. Const-HM: constant separation rate model, HM calibration. OJS: endogenous separation rate model with OJS. OJS-HM: endogenous separation rate model with OJS, HM calibration. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

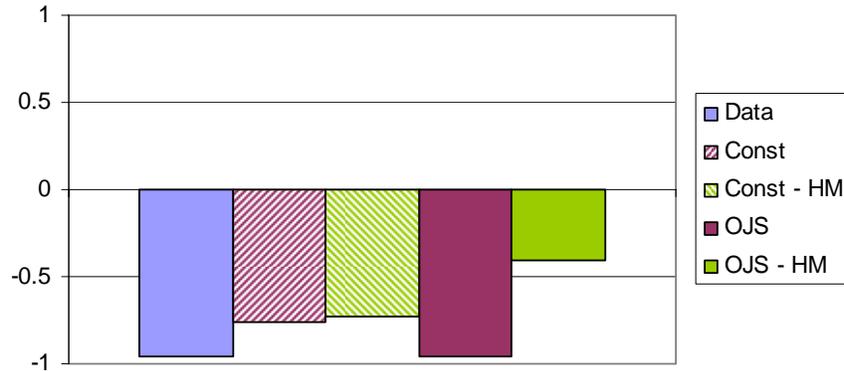
Figure 11. Vacancies and market tightness:
Standard and HM calibrations



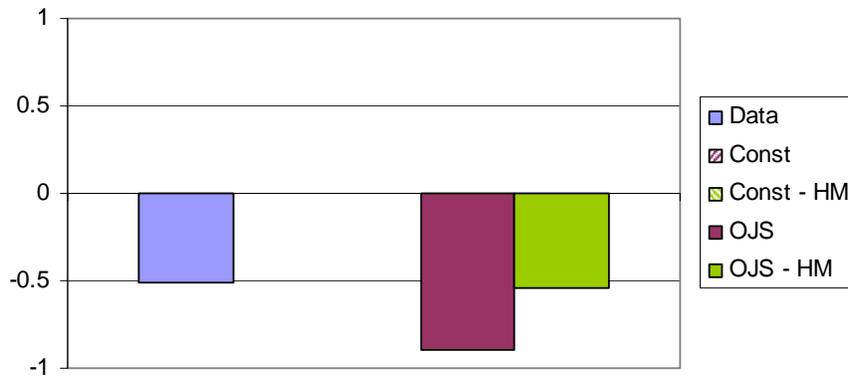
Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. Const-HM: constant separation rate model, HM calibration. OJS: endogenous separation rate model with OJS. OJS-HM: endogenous separation rate model with OJS, HM calibration. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.

Figure 12. Contemporaneous correlations:
Standard and HM calibrations

A. Unemployment and vacancies



B. Job finding and separation rates



Notes: Data: quarterly averages of monthly CPS series, 1976Q2-2005Q4, from Fujita and Ramey (2006). Series are logged and HP filtered, with smoothing parameter 1600. Statistics are taken from Table 2. Const: constant separation rate model. Const-HM: constant separation rate model, HM calibration. OJS: endogenous separation rate model with OJS. OJS-HM: endogenous separation rate model with OJS, HM calibration. See Table 1 for calibrations. Simulated data are quarterly averages of weekly series, logged and HP filtered, with smoothing parameter 1600. Each replication computes simulated statistics from a sample of 119 quarterly observations. Reported statistics are averages over 1000 replications.