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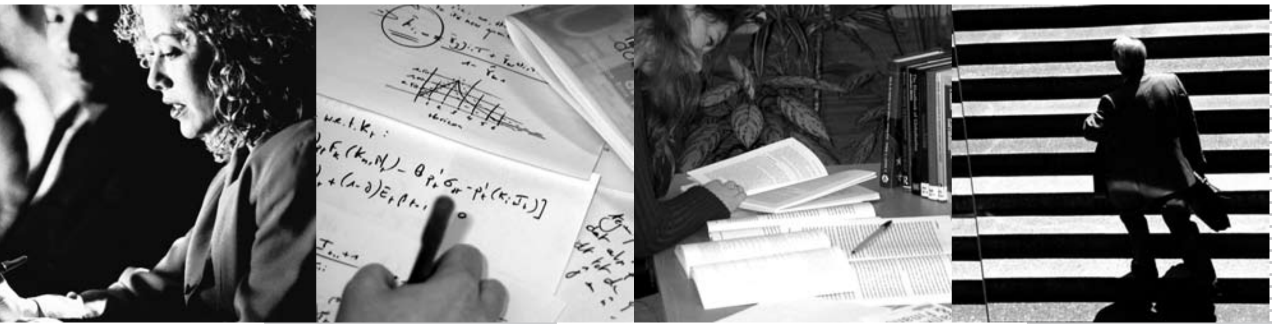

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INVESTMENT-SPECIFIC TECHONOLOGY SHOCKS AND LABOR MARKET FRICTIONS

Reinout De Bock (*)

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Abstract

This paper studies the implications of technical progress through investment-specific technical change in a business cycle model with search and matching frictions and endogenous job destruction. The interaction between the capital formation needed to reap the benefits of an investment-specific technology shock and gradual labor-market matching, generates hump-shaped, persistent responses in output, vacancies, and unemployment. The endogenous job destruction decision also leads to small but persistent endogenous fluctuations in total factor productivity. Simulations suggest a limited role for investment-specific technology shocks as a source of business cycle fluctuations compared to a standard real business cycle model.

JEL-code : E24, E32, J64

Keywords: LaborMarket Frictions, Investment-specific Technology Shocks, Business Cycles.

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1 Introduction

Over the past decade a number of empirical and theoretical contributions have argued investment-specific technology shocks are a promising avenue for modeling technology-driven business cycles (see Greenwood, Hercowitz, and Krusell (2000), Fisher (2006), and Justiniano and Primiceri (2006)). These shocks alter the cost of investment goods relative to consumption goods. The formation of new capital in turn generates output and employment fluctuations. As new capital goods take time to build, positive investment-specific technology shocks do not improve labor productivity on impact. This mechanism differs strongly from earlier work in the real business cycle tradition (RBC) where neutral technology shocks to total factor productivity affect the production of all goods homogeneously.[1]

The contribution of this paper is to evaluate the effect and quantitative role of investment-specific technology shocks in a vintage capital model with search and matching frictions.[2] The focus is on the interaction of the capital formation needed to reap the benefits of this type of shock in a model where labor adjustment is mainly driven by the movement of workers into and out of employment. More specifically, I introduce investment-specific technology shocks in a one sector business cycle model with capital accumulation and search and matching frictions. In the model households make aggregate consumption and investment decisions and rent capital to the firms. Employment adjustment at the firm level happens through endogenous changes in the job creation and destruction rate. Unlike Lopez-Salido and Michelacci (2005) who study permanent investment-specific technology shocks in a search model in which existing productive units fail to adopt the most recent technological advances, I assume changes in the rental rate of capital affect all units equally and evaluate the model's response to transitory shocks in the real price of investment.

In the business cycle model with search and matching frictions and exogenous job destruction studied in Merz (1995) and Andolfatto (1996), the impact of a neutral shock to output and its components is immediate and there is a gradual return of these variables to the steady state. In this sense a business cycle model with or without search frictions does not lead to wildly different output dynamics. den Haan, Ramey, and Watson (2000), on the other hand, embed the endogenous job destruction model of Mortensen and Pissarides (1994) in a business cycle setting and find substantial more propagation and persistence in model variables compared to standard RBC models or a model with exogenous job destruction.

Following an investment-specific technology shock, the responses of the business cycle model with endogenous job destruction studied in this paper are strikingly

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[1] The earlier contribution of Greenwood, Hercowitz, and Huffman (1988) notwithstanding.

[2] Dynamic general equilibrium models including the time-consuming process of matching unemployed workers with firms, have become an important tool for the study of cyclical labor adjustment. Merz (1995) and Andolfatto (1996) study search in a RBC model with risk aversion and capital accumulation. den Haan, Ramey, and Watson (2000) include endogenous job destruction in the model. Shimer (2005a) and Hall (2005) point out that the standard search and matching model driven by shocks in labor productivity is unsuccesful in accounting for the observed behavior of the job finding rate and vacancies. Mortensen and Nagypal (2005) survey this literature and show calibrated variants improve the model's ability to account for the observed volatility of the job finding rate.

different from that same model's responses to neutral technology shocks *and* the responses of a standard RBC model to an investment-specific technology shock. Given the time consuming matching of new workers, the endogenous response of the firms in the case of an expansionary investment-specific technology shock, is to increase hiring and decrease job destruction as the cost of capital falls. The interaction between the capital formation inherently needed for this type of shock and gradual labor-market matching is key for the propagation mechanism. The expected increase in future matching smooths the demand for capital. Capital supply and the equilibrium capital stock respond likewise and the output effect of the shock is magnified. Quantitatively evaluating the model reveals the shock has an impact magnification close to zero but generates hump-shaped, persistent responses in output, vacancies, and unemployment. Unlike the model with neutral shocks studied in den Haan, Ramey, and Watson (2000) and Fujita (2004), there is no echo-like fast return to steady state in the vacancy series. Different from the indivisible labor model of Hansen (1985), the model generates a hump-shaped response in output following an investment-specific technology shock. Cogley and Nason (1995) and Rotemberg and Woodford (1996) argue standard RBC models have weak internal propagation mechanisms as output dynamics mimic those of the underlying exogenous shock. In the search model, however, output peaks about fifty quarters after the autoregressive investment-specific technology shock hits. Business-cycle moments suggest investment-specific technology shocks account for less of the cyclical variation in output compared to the indivisible labor model.

Section 2 briefly describes some facts on the real price of investment and the cyclical properties of the US labor market. Section 3 lays out the model. Section 4 discusses the calibration values. Section 5 offers the simulation exercise. Section 6 concludes.

2 Stylized Facts

2.1 Real Price of Investment

The notion that innovations in the productivity of capital goods have implications for the aggregate economy is not new. In the General Theory for example, Keynes (1936) argues shocks to the marginal productivity (or efficiency) of investment goods are one of the main propagation mechanism for output fluctuations. The past decade a growing literature has questioned the common assumption of the earlier business cycle literature that technological change improves the production of consumption and investment goods homogeneously. This agenda is motivated by the observed trend and cyclical behavior of the price of business equipment (or investment goods) relative to the price of consumption goods (see Gordon (1989)). The upper panel of figure 1 plots the measure for the real price of investment as constructed in Fisher (2006). This price displays a secular downward trend between 1948 and 2004. In almost every year since the end of the 1950s, business equipment has become cheaper in terms of its value in consumption goods. Ceteris paribus an improvement in investment-specific technology (e.g. a processor's speed doubling every 18 months) then lowers the cost of investment goods relative to other goods. Employing a competitive equilibrium assumption, economists have used such price data as a proxy for investment-specific technology shocks over this period. Greenwood, Hercowitz, and Krusell (1997), for example, find capital-embodied technological changes are an important engine of long term economic growth.

The negative comovement between detrended real equipment investment and its real price suggests these technology shocks could be important business-cycle supply shocks. Greenwood, Hercowitz, and Krusell (2000) quantitatively investigate a model with investment-specific technological change as sole source for output fluctuations and find it can account for about 30% of output fluctuations. Using an identification scheme motivated by three long-run restrictions of the conventional real business cycle model, Fisher (2006) examines the importance of permanent neutral and investment-specific technology shocks as driving forces behind the business cycle variation in hours worked and output and finds investment-specific technology shocks have large effects on short-run fluctuations.

2.2 Business Cycle Properties US Labor Market

Table 1 reports correlations and standard deviations relative to output for the business cycle component of worker flows, job flows, unemployment and vacancies. The ins^{AZ} ratio is constructed from the Current Population Survey (CPS) worker flows data as the total flows into employment from unemployment and out-of-the-labor-force, scaled by the total employment stock. The outs ratio $outs^{AZ}$ is the total flows out of employment to unemployment and out-of-labor-force, again scaled by total employment stock. JCR^{DFH} and JDR^{DFH} are the quarterly job creation and destruction rates constructed from three sources by Faberman (2004) and Davis, Faberman, and Haltiwanger (2005).[3] Job creation is defined as the sum of employment gains at all plants that expand or start up between $t-1$ and t. Job destruction, on the other hand, sums up employment losses at all plants that contract or shut down between $t-1$ and t. Both measures are divided by the averages of employment at $t-1$ and t to obtain the creation and destruction rates JCR^{DFH} and JDR^{DFH}. Appendix A further discusses the construction of the worker and job flows data.

The table confirms some of the empirical regularities documented in the literature. Vacancies v are strongly procyclical whereas unemployment u is strongly countercyclical. There is a strong negative correlation between vacancies and unemployment. Job creation is moderately procyclical. Job destruction and the unemployment rate are countercyclical. Job destruction is one-and-a-half times more volatile than job creation. The latter observation motivated the search model with endogenous job destruction developed by Mortensen and Pissarides (1994).

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[3] The authors splice together data from the (i) BLS manufacturing Turnover Survey (MTD) from 1947 to 1982, (ii) the LRD from 1972 to 1998, and (iii) the Business Employment Dynamics (BED) from 1990 to 2004. The MTD-LRD data are spliced as in Davis and Haltiwanger (1999) whereas the LRD-BED splice follows Faberman (2004). See Braun, De Bock, and DiCecio (2006) for more on worker and job flows data.

The table also points to a less appreciated fact, i.e. the ins and outs ratios ins^{AZ} and $outs^{AZ}$ defined from worker flows have significantly different cyclical properties from the job creation and destruction series JCR^{DFH} and JDR^{DFH} and this despite definitional similarities. The standard deviations of the ins and outs ratio are about half the standard deviations of the job creation and destruction rates. The job creation and destruction rate are negatively correlated, whereas the correlation between the ins and outs ratios is positive. Furthermore, ins^{AZ} is negatively correlated with output, whereas the correlation of job creation with output is positive. Measuring ins and outs of *employment* using CPS worker flows, suggests the ins and the outs are equally volatile. In the model simulations below I compare the standard deviations of the in and outflows implied by the model with the standard deviations of both ins^{AZ} and $outs^{AZ}$ (worker flows data) and JCR^{DFH} and JDR^{DFH} (job flows data).

3 A Search and Matching Model with Capital Accumulation

3.1 Households

Each household is endowed with a unit of labor which is supplied inelastically to the labor market. A representative household maximizes the expected-utility function:

$$\max_{\{C_t\}} \mathbf{E}_0 \sum\nolimits_{t=0}^{\infty} \beta^t \left[\frac{C_t^{1-\sigma}}{1-\sigma} + (1-\kappa_t)b - \kappa_t h \right], \tag{1}$$

where C_t is consumption. If the agent works ($\kappa_t = 1$), he suffers a disutility h. If unemployed ($\kappa_t = 0$), he enjoys b, the value of leisure or household production. Households pool their incomes at the end of the period. Merz (1995) and Andolfatto (1996) argue perfect income insurance of heterogenous households leads to the above representative agent form. The household's budget constraint is:

$$C_t + I_t \leq \Pi_t + R_t^k K_t + W_t. \tag{2}$$

Household own and rent out capital to the firms at rental rate R_t^k and receive profits Π_t and capital income $R_t^k K_t$. Labor income is W_t. The evolution of the capital stock is given by:

$$K_{t+1} = (1-\delta)K_t + z_t I_t \tag{3}$$

$$Z_t = Z_{t-1}^{\rho_z} \exp(\varepsilon_{zt}),$$

where Z_t is a technology shock affecting the productivity of new capital goods.[4] The productivity of the already installed capital stock is not directly affected by the

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[4] Greenwood, Hercowitz, and Krusell (1997) offer both theoretical and empirical arguments for the omission of the investment-specific technology shock from the resource constraint implied by this formulation.

new technology. The number of consumption units that must be given up to get an additional efficiency unit of new capital is $\frac{1}{Z_t}$ (I_t is expressed in consumption units in (2)). In the competitive equilibrium the real price of investment $P_{I,t}$ is the inverse of the investment-specific technology shock Z_t. Only innovations to Z_t have an effect on $P_{I,t}$.

This paper takes a private sector equilibrium approach. Households maximize (1) subject to (2) and (3). Taking first-order conditions and eliminating multipliers leads to:

$$C_t^{-\sigma} P_{I,t} = \beta \mathbf{E}_t C_{t+1}^{-\sigma} \left[(1-\delta) P_{I,t+1} + R_{t+1}^k \right]. \tag{4}$$

Equation (4) describes each household's intertemporal decision to optimally allocate investment into capital. The current utility cost of investing $P_{I,t}$ equals the present value, in utility terms, of what $P_{I,t}$ is worth in the next period after depreciation and the rental income.

3.2 Firms and Labor Market Frictions

Each good Y_{it} is produced by a firm i at time t using capital and labor as inputs. Workers are identical and the output for a job at firm i is:

$$A_t a_{ijt} k_{it}^{\alpha},$$

where A_t is a random aggregate disturbance. a_{ijt} is a match-specific disturbance for job j at firm i. This idiosyncratic, job-specific productivity is drawn from a distribution with c.d.f. $F(a)$ and support $[\underline{a}, \overline{a}]$ and is i.i.d. over time. A job is profitable if $a_{ijt} \geq \tilde{a}_{it}$, where $\tilde{a}_{it}$ is the cut-off productivity level. If $a_{it} < \tilde{a}_{it}$, a job is not profitable and the relationship is severed. Firms rent a unit of capital k_{it} at cost r_t^k from the households.

Total output at firm i is given by a production technology including the mass n_{it} of employment relationships, average per-job capital level k_{it}, the aggregate disturbance A_t, and the job mass of idiosyncratic productivities a at which firm i is producing:

$$Y_{it} = A_t k_{it}^{\alpha} \int_0^{n_{it}} \int_{\tilde{a}_{it}}^{\bar{a}} a f(a,n) da dn.$$

The identical worker assumption implies $f(a,n) = f(a)f(n)$. Because the mass of workers is uniformly distributed over $[0,1]$, $f(n) = 1$, the above expression simplifies to:

$$Y_{it} = A_t n_{it} k_{it}^{\alpha} \int_{\tilde{a}_{it}}^{\bar{a}} a f(a) da.$$

The assumptions on the labor market are standard in the search and matching literature. There is a continuum of identical consumer-workers with total mass equal to one. The function matching unemployed workers u and firms with vacant jobs v is $M : [0,1] \times R^{+} \rightarrow [0,1]$. This function represents meeting frictions and determines the instantaneous number of meetings as a function of the number of searchers on each side of the market. M is Constant Returns to Scale and bounded above by $min\left\{u,v\right\}$. The functional form for M is $M(u_t,v_t)=\mu u_t^{\xi}v_t^{1-\xi}$. ξ is the elasticity to unemployment and μ is an efficiency parameter. I also define $m(\theta_t)\equiv M(1,\theta_t)$ where $\theta=\frac{v_t}{u_t}$ measures the degree of labor market tightness. Every unemployed worker meets an employee with probability:

$$m(\theta_t)=\frac{M(u_t,v_t)}{u_t}=\mu{\theta_t}^{1-\xi}.$$

This is the job finding rate. The probability a vacancy contacts a worker is:

$$q(\theta_t)=\frac{m\left(\theta_t\right)}{\theta_t}=\mu{\theta_t}^{-\xi}.$$

The total flow of new hires for an individual firm in t+1 is $v_{it}q(\theta_t)$. The job destruction or separation rate ρ_{it} at firm i is given by the probability ρ^x of constant exogenous job separation and an endogenous component ρ_{it}^n:

$$\rho_{it}^n=\int_{\bar{a}}^{\tilde{a}_{it}}f(a)da=F(\tilde{a}_{it}).$$

The rate ρ_{it} at firm i is the sum of the exogenous separation rate ρ^x and an endogenously destroyed fraction ρ_{it}^n of the remaining jobs:

$$\rho_{it}=\rho^x+(1-\rho^x)F(\tilde{a}_{it}), \tag{5}$$

implying a survival rate $\varphi_t=(1-\rho^x)(1-F(\tilde{a}_{it}))$.

The total wage bill for a firm i is the product of the mass of employment relationships at time t and all wages in jobs with an idiosyncratic productivity level above the cutoff $\tilde{a}_{it}$:

$$W_{it}=n_{it}\int_{\tilde{a}_{it}}^{\bar{a}}w_t(a)f(a)da.$$

Firms choose capital, employment and numbers of job posted and destroyed to maximize profits. An individual firm i's expected revenues net of expenses at time t are:

$$\Pi_{it}=\mathbf{E}_0\sum_{t=0}^{\infty}\beta^t\frac{\lambda_t}{\lambda_0}\left[n_{it}\left[A_tk_{it}^{\alpha}\int_{\tilde{a}_{it}}^{\bar{a}}af(a)da-r_t^kk_{it}\int_{\tilde{a}_{it}}^{\bar{a}}f(a)da\right]-W_{it}-cv_{it}\right], \tag{6}$$

The discount term $\beta^t\frac{\lambda_t}{\lambda_0}$ is the marginal rate of substitution of the households. Profits are evaluated in terms of value attached to them by the households, the firms' owners. The employment flow equation for an individual firm is:

$$n_{it}=(1-\rho_{it-1})n_{it-1}+v_{it-1}q(\theta_{t-1}). \tag{7}$$

Equations (6) and (7) show search theory is an alternative way of introducing adjustment costs on labor. More specifically, the adjustment cost for labor is $\frac{c}{q(\theta_t)}(n_{it+1} - (1-\rho_{it})n_{it})$. This cost of adjustment is linear in n_{it+1} and the vacancy cost c and increasing in θ_t and ρ_{it+1}.

Assuming representative firms, I drop index i. The first order condition for capital k_t is:

$$A_t \alpha k_t^{\alpha-1} \int_{\tilde{a}_t}^{\bar{a}} a f(a) da = r_t^k \int_{\tilde{a}_t}^{\bar{a}} f(a) da. \tag{8}$$

Equation (8) states firms rent capital up to the point where the marginal benefit of an additional unit of capital in every job equals the rental cost. The efficiency equations for $\{n_t, v_t, \tilde{a}_t\}$ are:

$$\mu_t = A_t k_t^\alpha \int_{\tilde{a}_t}^{\bar{a}} a f(a) da - r_t^k k_t \int_{\tilde{a}_t}^{\bar{a}} f(a) da - \frac{\partial W_t}{\partial n_t} + \beta \mathbf{E}_t \left[(\frac{\lambda_{t+1}}{\lambda_t}) \mu_{t+1} (1-\rho_t) \right] \tag{9}$$

$$\frac{c}{q(\theta_t)} = \beta \mathbf{E}_t (\frac{\lambda_{t+1}}{\lambda_t}) \mu_{t+1} \tag{10}$$

$$n_t \left[A_t k_t^\alpha \frac{\partial \left(\int_{\tilde{a}_t}^{\bar{a}} a f(a) da \right)}{\partial \tilde{a}_t} + f(\tilde{a}_t) r_t^k k_t \right] - \frac{\partial W_t}{\partial \tilde{a}_t} = \beta \mathbf{E}_t \left[\frac{\lambda_{t+1}}{\lambda_t} \mu_{t+1} (1-\rho_x) f(\tilde{a}_t) n_t \right] \tag{11}$$

Multiplier μ_t is the shadow value of employment. To get an expression for the job creation condition, substitute (9) into (10):

$$\frac{c}{q(\theta_t)} = \beta \mathbf{E}_t (\frac{\lambda_{t+1}}{\lambda_t}) \left[A_{t+1} k_{t+1}^\alpha \int_{\tilde{a}_t}^{\bar{a}} a f(a) da - r_{t+1}^k k_{t+1} \int_{\tilde{a}_{t+1}}^{\bar{a}} f(a) da - \frac{\partial W_{t+1}}{\partial n_{t+1}} + (1-\rho_{t+1}) \frac{c}{q(\theta_{t+1})} \right]. \tag{12}$$

The first order condition for the treshold $\tilde{a}_t$ implies following expression for the job destruction condition:[5]

$$(r_t^k k_t + w_t(\tilde{a}_t) - A_t k_t^\alpha \tilde{a}_t) = (1-\rho_x) \frac{c}{q(\theta_t)}. \tag{13}$$

To solve for the treshold $\tilde{a}_t$, I specify the function $w_t(\tilde{a})$ in the next subsection. Imposing symmetry in equilibrium leads to following flow equations for the behavior of the aggregate labor market:

$$n_t = (1-\rho_{t-1}) n_{t-1} + v_{t-1} q(\theta_{t-1}) \tag{14}$$

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[5] From the Leibnitz'rule, the derivatives for the wage bill are:

$$\frac{\partial W_t}{\partial \tilde{a}_t} = n_t \left[-f(\tilde{a}_t) w_t(\tilde{a}_t) \right] \text{ and } \frac{\partial W_t}{\partial n_t} = \int_{\tilde{a}_t}^{\bar{a}} w_t(a) f(a) da.$$

$$u_t = 1 - n_t \tag{15}$$

The evolution of unemployment is given by:

$$u_{t+1} = u_t + \rho_t(1 - u_t) - \theta_t q(\theta_t) u_t.$$

In steady state, this expression determines the vacancy-unemployment locus or Beveridge curve:

$$u = \frac{\rho}{\rho + \frac{v}{u} q(\frac{v}{u})}.$$

Unlike the exogenous job separation case with ρ fixed, movements in $\tilde{a}$ can shift the vacancy-unemployment locus through ρ.

3.3 Wage Determination

The matching friction gives rise to a bilateral monopoly context. A multiplicity of allocations will satisfy the individual rationality constraint. I follow Mortensen and Pissarides (1994) by applying the Nash Bargaining Solution, where the wage w_t is determined as the outcome of a Nash bargain between firms and workers. Both firms and workers participate as long as the surplus $S(a) \geq 0$ and the individual rationality conditions $[J_t \geq 0] \cap [W_t \geq U]$ are satisfied.

3.3.1 Bellman equations

The workers' value functions in the unemployment and employment states satisfy:

$$U_t = b + \beta \mathbf{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[m(\theta_{t+1}) E_{t+1}(a) + (1 - m(\theta_{t+1})) U_{t+1} \right], \tag{16}$$

$$E_t(a) = w_t(a) + \beta \mathbf{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - \rho_{t+1}) E_{t+1}(a) + \rho_{t+1} U_{t+1} \right], \tag{17}$$

where only the value function for employment is a function of time-t idiosyncratic productivity.

The firms' value function for a job is:

$$J_t(a) = A_t k_t^{\alpha} a_t - r_t^k k_t - w_t(a) + \beta \mathbf{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - \rho_{t+1}) J_{t+1}(a) \right] \tag{18}$$

The free-entry condition results in:

$$\frac{c}{q(\theta_t)} = \beta \mathbf{E}_t \frac{\lambda_{t+1}}{\lambda_t} \left[(1 - \rho_{t+1}) J_{t+1}(a) \right]. \tag{19}$$

3.3.2 Wage Setting

Wage in equilibrium is derived from the maximization of the Nash product:

$$w = \arg\max_{w} (E(a) - U)^{\eta} J(a)^{1-\eta}, \tag{20}$$

where $\eta \, \epsilon (0,1)$ measures the bargaining power in a relationship. As in Mortensen and Pissarides (1994) proposition 1 derives the solution to (20).

Proposition 1 *The wage schedule solving (20) is given by:*

$$w(a) = \eta(Ak^{\alpha}a - r^k k + \theta c) + (1-\eta)b \tag{21}$$

Proof. The first-order condition for (20) is: $(1-\eta)(E(a)-U) = \eta J(a)$. In terms of equations of the previous section, this can be rewritten as:

$$w(a) - b + \beta\left[((1-\rho-m(\theta))(E(a)-U)\right] = \frac{\eta}{1-\eta}\left(Ak^{\alpha}a - r^k k - w(a) + \beta(1-\rho)J(a)\right).$$

Substituting $\beta J(a) = \frac{c}{q(\theta)}$ on the right hand side and the first order condition for the Nash product (20), $(E(a) - U) = \frac{\eta}{(1-\eta)} J(a)$, on the left hand side leads to (21). ■

The term $\theta c = \frac{cv}{u}$ is the average hiring cost for each unemployed worker. Under Nash bargaining workers are rewarded with a higher wage when hiring is more costly. Given the wage schedule (21), the wage bill at time t is:

$$\begin{aligned} W_t &= n_t \int_{\tilde{a}_t}^{\bar{a}} w_t(a_t) f(a) da \qquad (22) \\ &= n_t \left[\eta (A_t k_t^{\alpha} \int_{\tilde{a}_t}^{\bar{a}} a_t f(a) da - r_t^k k_t \int_{\tilde{a}_t}^{\bar{a}} f(a) da) + \eta \theta_t c \int_{\tilde{a}_t}^{\bar{a}} f(a) da + (1-\eta) b \int_{\tilde{a}_t}^{\bar{a}} f(a) da \right] \end{aligned}$$

Following proposition shows how to get an analytic expression for the job separation treshold $\tilde{a}_t$.

Proposition 2 *In equilibrium, the job destruction condition is given by:*

$$(1-\eta) r_t^k k_t + \eta \theta c + (1-\eta) b - (1-\eta) A_t k_t^{\alpha} \tilde{a}_t = (1-\rho_x) \frac{c}{q(\theta_t)}.$$

Proof. Take (13) and plug in $w(a)$ evaluated at $\tilde{a}$ and $\int_{\tilde{a}}^{\bar{a}} w(a) f(a) da$. ■

The left-hand side of the job destruction condition is the cost of keeping a job with productivity $\tilde{a}_t$ open. In equilibrium this equals the expected gain of a new job in the next period net of exogenous destruction.[6] There are, for example, two effects of θ on the job separation threshold $\tilde{a}$. On the one hand, workers find it easier to find new jobs when the labor market is tight. They require a higher share of the pie in

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[6] There is some labor hoarding in the model as firms pay a cost for keeping jobs open that could be profitable in the future.

the bargain. This effect increases wages and pushes up the job separation treshold. On the other hand, more vacancies for a given value of unemployment decrease the job-filling rate and firms destroy a job less easily.

Using the expression for the wage bill (22), it is possible to get a Mortensen and Pissarides (1994) style job creation condition.

Proposition 3 *In equilibrium, the job creation condition is:*

$$\frac{c}{q(\theta_t)} = \beta \mathbf{E}_t(\frac{\lambda_{t+1}}{\lambda_t}) \left[\begin{array}{c} (1-\eta)\left(A_{t+1}k_{t+1}^{\alpha}H(\tilde{a}_{t+1}) - r_{t+1}^{k}k_{t+1}\int_{\tilde{a}_{t+1}}^{\bar{a}} f(a)da - b\int_{\tilde{a}_t}^{\bar{a}} f(a)da \right) \\ -\eta\theta_t c\int_{\tilde{a}_t}^{\bar{a}} f(a)da + (1-\rho_{t+1})\frac{c}{q(\theta_{t+1})} \end{array} \right]$$

Proof. Take (12) and solve out the wage term using the wage schedule derived from the Nash bargain. ■

Expression (12) equates the cost of vacancy creation, the flow cost c times the expected duration it takes to fill the job, to the expected return of creating a new job.

3.3.3 Aggregate Wage

The aggregate wage is the weighted average of individual wages paid:

$$\begin{aligned} E(w(a) \quad | \quad a > \tilde{a}) &= \frac{1}{1-F(\tilde{a})}\int_{\tilde{a}_t}^{\bar{a}} w_t(a_t)f(a)da \\ &= \eta(A_t k_t^{\alpha}\frac{\int_{\tilde{a}_t}^{\bar{a}} a_t f(a)da}{1-F(\tilde{a})} - r_t^k k_t) + \eta\theta_t c + (1-\eta)b. \end{aligned}$$

The conditional expectation is increasing in $\tilde{a}_t$. Under endogenous job destruction, the margin of employment adjustment is at jobs with lower idiosyncratic productivities. The expected productivity of occupied jobs and the aggregate wage are increasing in $\tilde{a}_t$.

3.4 Closing the Model

Consumption and investment are related to employment and the stock of capital by:

$$Y_t = A_t n_t k_t^{\alpha}\int_{\tilde{a}_t}^{\bar{a}} af(a)da = I_t + C_t + cv_t. \tag{23}$$

The rental rate of capital R_t^k equals the cost of capital r_t^k so that aggregate capital demand is equal to the aggregate supply of capital:

$$n_t k_t \int_{\tilde{a}_t}^{\bar{a}} f(a)da = K_t. \tag{24}$$

The left-hand side of (24) is the total demand for capital, given by the number of employment relationships n_t times the total amount of capital chosen by the firm in all the filled jobs. K_t is total capital supplied by the households.

The shocks follow first-order autoregressive (AR(1)) processes:

$$\begin{aligned} A_t &= A_{t-1}^{\rho_a} \exp(\varepsilon_{at}) \\ Z_t &= Z_{t-1}^{\rho_z} \exp(\varepsilon_{zt}) \\ & [\varepsilon_{at}, \varepsilon_{vt}] \,\tilde{}\, N(0, D) \end{aligned} \tag{25}$$

3.5 Ins, Outs, Job Creation and Destruction

I define the creation rate ins_t in the model as new matches scaled by employment:

$$ins_t \equiv \frac{M(u_t, v_t)}{n_t}. \tag{26}$$

The separation rate $outs_t$ is defined as:

$$outs_t \equiv \rho_t. \tag{27}$$

The literature typically presents definitions for job creation and job separation where exogenous worker turnover ρ^x is subtracted from (26) and (27) as exogenous worker turnover is not considered a firm induced change in employment (see den Haan, Ramey, and Watson (2000)). In that case, ins_t and $outs_t$ are not the model counterparts of the job flows variables studied in Davis and Haltiwanger (1999) or Davis, Faberman, and Haltiwanger (2005). Job creation is defined as ins_t net of exogenous turnover:

$$jcr_t^{NET} \equiv \frac{M(u_t, v_t)}{n_t} - \rho^x. \tag{28}$$

Net job destruction is total separations $outs_t$ minus exogenous worker turnover:

$$jdr_t^{NET} \equiv \rho_t - \rho^x. \tag{29}$$

The net change in employment is the difference between (26) and (27) or between (28) and (29):

$$\frac{n_{t+1} - n_t}{n_t} \equiv ins_t - outs_t \equiv \frac{M(u_t, v_t)}{n_t} - \rho_t \equiv jcr_t^{NET} - jdr_t^{NET} \tag{30}$$

3.6 Job Destruction and Total Factor Productivity

Lagos (2006) derives an aggregate production function in the model of Mortensen and Pissarides (1994) by aggregation across jobs and shows the level of total factor productivity (TFP) of the production function depends on labor market characteristics. Interestingly, in models with an endogenous job destruction decision exogenous movements in the price of investment can drive TFP through fluctuations in the rate of endogenous separations. To see this consider the production function in (23),

$Y_t = \left[A_t \int_{\tilde{a}_t}^{\bar{a}} af(a)da\right] n_t k_t^{\alpha}$. In equilibrium equation (5) $K_t = n_t k_t(1 - F(\tilde{a}_t))$ holds, so Y_t can be rewritten as:

$$\begin{aligned} Y_t &= \left[A_t \int_{\tilde{a}_t}^{\bar{a}} af(a)da\right] n_t^{1-\alpha} \left(\frac{K_t}{(1-F(\tilde{a}))}\right)^{\alpha} \\ &= \left[A_t \frac{\int_{\tilde{a}_t}^{\bar{a}} af(a)da}{(1-F(\tilde{a}_t))}\right] \left[(1-F(\tilde{a}_t))n_t\right]^{1-\alpha} K_t^{\alpha}. \end{aligned}$$

Average idiosyncratic job productivity is the conditional expectation $G(\tilde{a}) = E(a \mid a > \tilde{a}) = \frac{\int_{\tilde{a}_t}^{\bar{a}} af(a)da}{(1-F(\tilde{a}_t))}$. Define TFP_t as:

$$TFP_t = A_t G(\tilde{a})$$

Loglinearizing this expression leads to:

$$\widehat{TFP}_t = \hat{A}_t + \left[\frac{G'(\tilde{a})}{G(\tilde{a})}\right] \tilde{a}\widehat{(\tilde{a}_t)}, \tag{31}$$

where hats denote percentage deviations from steady state. To evaluate the role of job separations, loglinearize $\rho_t = \rho^x + (1-\rho^x)F(\tilde{a}_t)$, $\widehat{\rho}_t = \frac{(1-\rho^x)}{\rho} f(\tilde{a})\tilde{a}\widehat{(\tilde{a}_t)}$, and substitute $\widehat{\tilde{a}}_t$ out of expression (31):

$$\widehat{TFP}_t = \hat{A}_t + \frac{G'(\tilde{a})}{G(\tilde{a})} \frac{\rho}{f(\tilde{a})(1-\rho^x)} \widehat{\rho}_t.$$

The distribution $F(\cdot)$ and the degree of exogenous turnover determine the elasticity of the level of TFP or output with respect to job destruction ρ. The positive coefficient on $\widehat{\rho}_t$ expresses the effect more job destruction has on total factor productivity by increasing average idiosyncratic productivity ($G'(\tilde{a}) > 0$ as jobs with lower idiosyncratic productivities are destroyed first).

3.7 Equilibrium

A private sector equilibrium is a set of allocations $\{C_t, K_{t+1}, I_t, Y_t, k_t, n_t, v_t, \tilde{a}_t\}$ and prices $\{P_{I,t}, R_t^k, r_t^k, w_t(a)\}$ such that:

- $\{C_t, K_{t+1}\}$ solves the household's problem (1) subject to the budget constraint (2) and the capital accumulation technology.
- Firms optimize, they choose $\{k_t, n_t, v_t, \tilde{a}_t\}$ to maximize profits (6) subject to the employment flow equation (7).
- Markets clear. Capital demand in period t is equal to the supply of capital (24) and the resource constraint (23) holds.
- Laws of motion for the number of relationships and the number of unemployed workers, are given by (14) and (15).
- Wages $w_t(a)$ are determined by Nash bargaining after matching.

4 Calibration

4.1 Preferences, Capital Share and Depreciation

The upper panel of table 2 displays the parameter values for β, α, δ and σ. In this model α corresponds to an output/capital ratio of about ten percent. The coefficient of relative risk aversion $\sigma = 1$ corresponds to the logarithmic utility function.

4.2 Labor Market

The calibrated values of key labor market parameters are derived from a number of empirical studies. The lower panel of table 2 summarizes the parameterization of the labor market. Unemployment covers both those who are not in the labor force but "want a job" and the officially unemployed. Its data estimation for 1968-1986 is $u = 0.11$ (see Blanchard and Diamond (1990)).

Petrongolo and Pissarides (2001) survey the evidence on the matching function. According to most studies, a loglinear approximation fits the data well. The estimated functions typically satisfy constant returns to scale. When the dependent variable is the total outflow from unemployment, an estimation for the elasticity on unemployment ξ is about 0.7, implying an elasticity on vacancies of about 0.3. More generally, Petrongolo and Pissarides (2001) consider 0.5 to 0.7 a plausible range for the estimated unemployment elasticity. In the calibration I set ξ equal to 0.7.

As in Cole and Rogerson (1999) and den Haan, Ramey, and Watson (2000) I set the job-filling probability $q(\theta)$ to be equal to 0.7. In a quarterly setting, this implies that the average time it takes to fill a vacancy is about a quarter and a half. den Haan, Ramey, and Watson (2000) cite empirical studies that find similar values. The value for the job-finding rate $m(\theta)$ is pinned down from the steady state relationships.[7]

There exist several measures for the job separation parameter ρ. In a survey paper Hall (1995) finds that quarterly US separation rates lie in the range of 8 to 10%. Davis, Haltiwanger, and Schuh (1996) get an annual separation rate of 36.8% from the CPS. den Haan, Ramey, and Watson (2000) set the steady state separation rate ρ equal to 0.1. This is the value I use as it corresponds to the value reported in the CPS where workers are asked how long ago they began their current jobs (the shortest category, however, is 6 months). A fundamental question is how to distinguish the endogenous from the exogenous component of the separation rate. den Haan, Ramey, and Watson (2000) assume exogenous separations are worker-initiated (so worker turnover) so that the endogenous job separation rate corresponds to the permanent lay-off rate. I take the estimate of Topel (1990) from the Panel Study of Income Dynamics (PSID) for the quarterly permanent layoff rate at 0.018.[8] In Hall (1995) this value is the upper

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[7] Clark and Summers (1979) correct for the downward bias in measured unemployment spells and estimate average unemployment duration at 19.9 weeks in 1974, which corresponds to a value of $m(\theta) = 0.60$. More recently, Polivka and Rothgeb (1993) find that the duration of unemployment in the unrevised pre-1994 Current Population Survey (CPS) was not reported consistently for individuals who had been unemployed in previous months.

[8] See figure 1 in Topel (1990). This is the quarterly adjusted frequency of job loss from employer going out of business, layoff, or firing, and completion of job reported in the PSID (unadjusted

estimate for separations initiated by employers where workers had held long-term jobs.

From ρ_n, I get the treshold $\tilde{a}$ by taking the inverse of the cumulative distribution function $F^{-1}(\rho_n)$. An often used distributional assumption for a_t is the lognormal one:

$$\log a_t \sim N(\mu_a, \sigma_a^2),$$

Under the distributional assumption of lognormality, I obtain an expression for $\int_{\tilde{a}}^{\bar{a}} af(a)da$ and the conditional expectation of the aggregate wage.[9] Unfortunately microstudies offer no empirical counterparts for $\tilde{a}, \mu_a$ and σ_a^2. These are key parameters in the model, determining the elasticity of output or total factor productivity with respect to gross job destruction ρ_t (see subsection 3.6). I follow den Haan, Ramey, and Watson (2000) and Krause and Lubik (2005) by normalizing $E(log(a_t)) = \mu_a = 0$ and fix σ_a at 0.12, in range of the values used by these authors.[10] The vacancy cost c and the value of leisure/ household production are determined by the steady state conditions. The obtained value for b yields a replacement ratio while searching of about 80 percent of the average aggregate wage. The value for the vacancy cost implies cv_t is about a percent of total output.

4.3 Stochastic Processes for the Shocks

The processes for both technology shocks is written jointly as:

$$\begin{bmatrix} \ln(A_t) \\ \ln(Z_t) \end{bmatrix} = \begin{bmatrix} \rho_a & 0 \\ 0 & \rho_z \end{bmatrix} \begin{bmatrix} \ln(A_{t-1}) \\ \ln(Z_{t-1}) \end{bmatrix} + \begin{bmatrix} \varepsilon_{at} \\ \varepsilon_{zt} \end{bmatrix},$$

where zero correlation is assumed:

$$\begin{bmatrix} \varepsilon_{at} \\ \varepsilon_{zt} \end{bmatrix} \sim N\left(\begin{matrix} 0 \\ 0 \end{matrix}, \begin{bmatrix} \sigma_a & 0 \\ 0 & \sigma_z \end{bmatrix} \right).$$

As in Hansen (1985), the logarithm of the neutral technology shock A_t follows an AR(1) process with coefficient $\rho_a = 0.95$ and a standard deviation $\sigma_a = 0.007$.

To simulate the model's response to innovations in investment-specific technology, I need to specify the process for the investment specific shocks Z_t in (25). Greenwood,

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annual rate is 7.0 percent per year)

[9] The mean θ and variance λ^2 of a lognormal distribution with parameters μ and σ^2 are given by $\theta = \exp(\mu + \frac{1}{2}\sigma^2)$ and $\lambda^2 = \exp(2\mu + \sigma^2)(\exp(\sigma^2) - 1)$. Alternatively, given the mean and variance of a lognormal distribution, one can then calculate μ and σ^2 of the associated normal where $\mu = 2\ln\theta - \frac{1}{2}\ln(\theta^2 + \lambda^2)$ and $\sigma^2 = \ln(1 + \lambda^2/\theta^2)$. The mean of the truncated distribution is then:

$$E(a \mid a > \tilde{a}) = \frac{\int_{\tilde{a}}^{\bar{a}} af(a)da}{1 - F(\tilde{a})} = E(a)\frac{1 - \Phi(\gamma - \sigma)}{1 - \Phi(\gamma)},$$

where $\gamma = [\log(\tilde{a}) - \mu]/\sigma$ and $\Phi(\cdot)$ denotes the cumulative distribution function of the standard normal.

[10] This choice is for comparison with the existing literature. Evaluating the model across (μ_a, σ_a)-pairs shows different values affect the propagation effect of a technology shock and the volatility of key variables in the model such as job creation, destruction, vacancies and unemployment.

Hercowitz, and Krusell (2000) estimate the process Z_t as an AR(1) on the inverse of the real price of equipment $P_{E,t}$:

$$\ln(1/P_{E,t}) = k + t\ln(\gamma_q) + \ln(Z_t),$$

where k is a constant, t the linear trend and Z_t is given by:

$$\ln(Z_t) = \rho_z \ln(Z_{t-1}) + \varepsilon_{zt} \text{ with } 0 < \rho_z < 1 \text{ and } \varepsilon_{zt} \sim N(0, \sigma_z). \tag{32}$$

Greenwood, Hercowitz, and Krusell (2000) point out the direct estimation of the process for investment-specific technological change has an advantage over real business cycle models driven by an imputed "Solow residual" as this residual could be affected by other factors besides technology. For the 1967Q2-2004Q2 quarterly sample of the real price of investment used by Fisher (2006), the estimated equation (32) is:

$$\begin{aligned} \ln(1/P_{I,t}) &= k + t\underset{(4.5)}{0.01} + \ln(Z_t), && (33) \\ \ln(Z_t) &= \underset{(96)}{0.98}\ln(Z_{t-1}) + \varepsilon_{zt} \text{ and } \varepsilon_{zt} \sim N(0, 0.007). \end{aligned}$$

The numbers in parentheses are t statistics. I use the parameters $\rho_z = 0.98$ and $\sigma_z = 0.007$ in the simulation.

5 Simulation Analysis

This section first evaluates the response of the model economy to neutral technology shocks before turning to the investment-specific shocks in the second subsection. Different from earlier contributions that solely focus on the job flow variables, I also compare business cycle statistics for the simulated series *ins* and *outs* and the variables ins^{AZ} and $outs^{AZ}$ constructed from three-pool CPS worker flows data.[11] As a model benchmark, the search economy is evaluated along with a similarly calibrated indivisible labor model. This model was first proposed in Hansen (1985) and is a popular variant of the RBC model incorporating households' substitution of labor between employment and nonemployment (extensive margin). The above model is non-linear.[12] I solve the model by taking a second-order approximation to the policy functions as described in Schmitt-Grohe and Uribe (2004).

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[11] Mortensen and Pissarides (1994), den Haan, Ramey, and Watson (2000), Krause and Lubik (2005), compare model moments with moments from the job flows data. Fujita (2004) uses CPS worker flows data, together with the vacancy series, in a trivariate vector autoregression but does not compare unconditional business cycle moments.

[12] The above model can be approximated in (log)linearized form as $x_t = Ax_{t-1} + h_t$. Blanchard and Kahn (1980) state the necessary and sufficient condition for this equation to determine a unique and stable path: matrix A has as many eigenvalues of absolute values smaller than one as there are predetermined endogenous variables and as many eigenvalues or absolute values larger than one as there are anticipated variables. Krause and Lubik (2004a) show indeterminacy and non-existence of equilibrium are possible in a business cycle model with search frictions, but these do not arise for the above parametrizations.

5.1 Neutral Technology Shocks

Figure 2 presents impulse responses in steady-state percentage deviations to a one standard deviation neutral technology shock for output, labor productivity, investment, *ins*, *outs*, unemployment, and vacancies. The upper left panel shows that, following a positive productivity shock, adjustment of output towards the steady state is much slower than the adjustment of the exogenous shock. Output dynamics follow the dynamics of the productivity shock less closely than in the indivisible labor model. Table 3 reports the *impact magnification* and *total magnification* of a neutral technology shock for both the indivisible labor and search model. Impact magnification is defined as the change in output at the moment a shock hits relative to the standard deviation of the productivity shock. Total magnification is the ratio of the standard deviation of unfiltered output in model simulations to the standard deviation of the productivity shock. Compared to the indivisible labor model, table 3 indicates a lower impact magnification but similar total magnification in the search model. The figure and table confirm the results of den Haan, Ramey, and Watson (2000): embedding the endogenous job destruction model of Mortensen and Pissarides (1994) in a business cycle model, magnifies the output effect of neutral technology shocks and makes model variables more persistent.

As established in Fujita (2004), a search model with endogenous job destruction fails to generate vacancy persistence and the mirror-like behavior of vacancies and unemployment observed in the data. The lower panel of figure 2 shows there is a sharp and immediate response of vacancies and unemployment to the shock. The impulse responses are asymmetric; the response of unemployment is persistent but vacancies return close to steady state with no delay and display no persistence. There is an echo in the vacancy series as this variable returns to steady state at a much faster rate then the other variables. A positive neutral technology shock increases the expected returns of posting. Given the free entry condition, the expected returns to a vacancy posting are equal to the vacancy cost and firms post vacancies as long as this is expected to be profitable. Vacancy posting and reduced job destruction, lower future unemployment. The odds for a firm to find an unemployed worker worsen, lowering the incentive to post vacancies. This is the echo and as a result vacancies converge too fast to the steady state. The autocorrelation function of the vacancy series on the third row in table 5 is symptomatic. Vacancies are highly autocorrelated in the data but the model fails to replicate this pattern. Table 4 presents dynamic correlations between unemployment and vacancies. The model generates a negative correlation between vacancies and unemployment despite the lack of autocorrelation in the vacancy series. As illustrated in figure 2, *ins* increases on impact but the decrease in unemployment drives *ins* below steady state value in the following periods. The impulse response functions of *outs* and *ins* behave very similar after the first period.[13]

Table 6 reports an evaluation of the basic business cycle statistics for the indivisible labor and search model. Per column the table offers the results of simulations where either neutral (Neut) or investment-specific (Inv) technology shocks are the

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[13] den Haan, Ramey, and Watson (2000) find a similar pattern for the impulse response functions of job creation and job destruction after a neutral technology shock.

only exogenous driving forces. The upper panel statistics for the search economy with neutral shocks are along the lines of den Haan, Ramey, and Watson (2000). The lower panel of table 6, on the other hand, offers a couple of new observations. Different from previous contributions that solely focus on job flows data, I compare volatilities of the simulated series ins and $outs$ and the variables ins^{AZ} and $outs^{AZ}$ constructed from the three-pool CPS worker flows data. Interestingly, the model matches a sizable fraction of the observed standard deviations of the ins^{AZ} and $outs^{AZ}$ and captures the relatively higher volatility of ins^{AZ}. The volatility of job destruction net of worker turnover, jdr^{NET}, replicates the volatility of the job destruction variable JDR^{DFH} constructed in Faberman (2004) and Davis, Faberman, and Haltiwanger (2005). The volatility of job creation net of worker turnover jcr^{NET} overstates the volatility of observed job creation JCR^{DFH}. In fact, the model variable jcr^{NET} is twice as volatile as JCR^{DFH}. The model also fails to reproduce the observed volatility of unemployment and vacancies but lacks important features such as on-the-job search or a labor force participation decision associated with vacancy posting and unemployment transitions.[14]

5.2 Investment-Specific Technology Shocks

5.2.1 Impulse Response Dynamics and Business Cycle Moments

Figure 3 prints impulse responses in steady-state percentage deviations to a one standard deviation expansionary investment-specific technology shock for output, labor productivity, investment, ins, outs, unemployment, and vacancies. In response to the investment-specific technology shock there is an investment boom in both the indivisible labor and search model as households take maximum advantage from the temporary improvement in the production of capital goods and substitute current consumption for future consumption. The positive shock leads to an increase in the supply of capital and a decrease in the rental rate of capital. In the search model, the response of firms is to increase employment via reduced job destruction and time-consuming matching. Higher future employment will in turn increase the future demand for capital. The endogenous response of the households is to smooth the response of investment and the supply of capital. This magnifies the output effect of the shock. Table 3 shows the shock has an impact magnification of zero in the search model (compared to 0.73 in the case of the indivisible labor model). Total magnification, on the other hand, is 2.27 (compared to 3 in the indivisible labor model), indicating significant persistence generated by the search model. To graphically illustrate the persistent output effects generated by the search model, figure 4 presents impulse responses 200 periods out. In the indivisible labor model output peaks on impact, whereas output peaks about 50 quarters after the shock initially hits in the search model. Also, labor productivity falls on impact in the indivisible labor model and not in the search model.

The lower panel of figure 3 shows that an investment-specific technology shock has different implications for the behavior of vacancies compared to the neutral technology

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[14] See Krause and Lubik (2004b) and Nagypal (2006).

shock case. Following the shock, there is a hump-shaped increase in vacancies and a hump-shaped decline in unemployment. There is no echo-like fast return to steady state in the vacancy series. Table 5 shows that the generated vacancy series is highly autocorrelated. Table 4 reports that both vacancies and unemployment are negatively correlated. The impulse responses for *ins* and *outs* in figure 3, on the other hand, comove positively.

The persistent dynamics generated by the search model, lower the business cycle contribution of these shocks. From table 6 the fraction of observed output explained by the investment-specific technology shock would be $0.67/1.57 = 42\%$ in the indivisible labor and $0.10/1.57 = 6\%$ in the search economy. In the model with search frictions investment-specific technology shocks diffuse slowly in the economy.[15] Regressing filtered TFP_t on its lagged value, demonstrates that the endogenous job destruction decision leads to small but persistent endogenous fluctuations in total factor productivity:

$$\log(TFP_t) = 0.96 \log(TFP_{t-1}) + \varepsilon_{TFP,t} \text{ and } \varepsilon_{TFP,t} \sim N(0, 0.00001),$$

where $\rho_{TFP} = 0.96$ and $\sigma = 0.00001$ are averages over 100 simulations of 200 periods.

5.2.2 Role of Labor-Market Matching and Job Destruction

This subsection examines the propagation mechanism implied by labor-market matching and the endogenous job destruction decision by evaluating the economy's response to a one-time investment-specific technology shock without persistence ($\rho_z = 0$). Also, I fix the coefficient of relative risk aversion σ close to zero, making households utility linear in consumption and removing the consumption-smoothing mechanism.[16] The economy is in steady state in period $t = 0$. The values for the rental rate and capital are $r^k_{SS} = \frac{1}{\beta} - (1 - \delta)$ and K_{SS} respectively. In period $t = 1$ the economy is hit by a one time increase in the relative price of investment $P_{I,1} > 1$.

Figure 5 illustrates the effect this shock has on the capital market in the two periods $t = 2, 3$ following the shock. The one-time shock increases the rental rate of capital in period $t = 2$ (given linear utility the rental rate is given by $r^k_2 = \frac{P_{I,1}}{\beta} - (1-\delta)$), shifting the capital supply curve up in period $t = 2$. From the firm's first-order condition for capital in (8), the upward shift in r^k_2 lower the firm's demand for capital k_t:

$$k_2 = \left(\frac{\alpha}{r^k_2}\right)^{\frac{1}{1-\alpha}} \left(\frac{\int_{\tilde{a}_2}^{\bar{a}} af(a)da}{1 - F(\tilde{a}_2)}\right)^{\frac{1}{1-\alpha}}.$$

Substituting k_2 into the capital market clearing condition (24) leads to the aggregate capital demand curve:

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[15] This results is in line with Rotemberg (2003).

[16] Section 2 of den Haan, Ramey, and Watson (2000) carries out a similar type of exercise for the neutral technology shock.

$$n_2 \left(\frac{\alpha}{r_2^k}\right)^{\frac{1}{1-\alpha}} \left(\frac{\int_{\tilde{a}_2}^{\bar{a}} af(a)da}{1-F(\tilde{a}_2)}\right)^{\frac{1}{1-\alpha}} (1-F(\tilde{a}_2)) = K_2^D. \quad (34)$$

Equation (34) indicates job destruction plays a role in the propagation of the shock. Firms can contemporaneously respond to the higher cost of capital by adjusting the treshold $\tilde{a}_2$. Figure 6 prints the model impulse responses. Output responds with a lag to the shock in $t = 2$. The spike in job destruction in $t = 2$ and the search for new workers afterwards implies employment n_t is lower in future periods ($t \geq 3$), when the rental rate is back at steady state. Given the below steady-state employment in period 3, the capital market will clear at a level K_3^D below the steady state K^{SS} and the output effect of the shock is magnified. Figure 6 also evinces the muted response of job destruction and consequent reduction in overall propagation when the endogenous job destruction component is reduced ($\rho_x = 0.099$ close to $\rho = 0.10$).

5.2.3 Robustness

The literature abounds with different calibrations for labor market parameters. For robustness with respect to the conclusion of a limited role for investment-specific technology shocks as a source of business cycle fluctuations, this subsection evaluates changes to key parameters. The results are summarized in table 7.[17]

Level of Unemployment Merz (1995) uses $u = 0.07$, Andolfatto (1996) 0.15, and Hall (2005) 0.06. The latter value for u does not change the quantitative conclusions.

Worker Bargaining Power Decreasing the worker bargaining power η increases the fixed component b of the wage. The literature has argued that a higher value of b relative to the wage increases the model's performance with respect to the volatility of unemployment and vacancies.[18] The table demonstrates a lower $\eta = 0.15$ more than doubles the volatility of vacancies and unemployment, lowers the autocorrelation in the vacancy series but increases the volatility of output only marginally.

Low Endogenous Job Destruction Component Increasing the exogenous component ρ^x of the separation rate $\rho = 0.1$, lowers the volatility of unemployment, job creation, and job destruction and increases that of vacancies. Vacancies and unemployment become more negatively correlated, a result also found in Krause and Lubik (2005) in the context of money and neutral-technology shocks. The volatility of output does not change by much.

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[17] There is an important caveat to this type of exercise. The calibrated values of household production b and the vacancy cost c are determined by the steady condition of the search model. Changing values for key parameters such as unemployment or the bargaining share also alters the level of e.g. the average wage vis-à-vis the average productivity or can push the model into indeterminacy.

[18] See Cooley and Quadrini (1999).

6 Conclusion

This paper has studied investment-specific technology shocks in a business cycle model with labor-matching. Compared to a standard business cycle model, search frictions reduce the importance of these shocks as a source of business cycle fluctuations. The frictions do generate hump-shaped and persistent responses to key variables such as output, unemployment and vacancies. Together with Lopez-Salido and Michelacci (2005), the paper is a starting point to think about the role these shocks play in the business cycle in the presence of labor market frictions. Further empirical and theoretical research is needed to improve our understanding of this type of shock and its interaction with job creation, job destruction, worker turnover, and total factor productivity.

In addition the paper has pointed out that similarly defined objects from worker and job flows exhibit different business cycle dynamics. Mortensen and Pissarides (1994) focus on the role of match heterogeneity for job flows dynamics. This paper has shown that a business cycle version of the Mortensen and Pissarides (1994) model with neutral or investment-specific technology shocks, cannot capture the volatility of *both* job and worker flows variables. In particular, the model as calibrated above overstates the volatility of job creation. The development of a business cycle model along the lines of Lagos and Kiyotaki (2006) that matches the observed differences in volatility and correlation pattern of job and worker flows variables at business cycle frequencies, is certainly worth pursuing.

References

Abowd, J. M., and A. Zellner (1985): "Estimating Gross Labor-Force Flows," *Journal of Business and Economic Statistics*, 3(3), 254–83.

Andolfatto, D. (1996): "Business Cycles and Labor-Market Search," *American Economic Review*, 86(1), 112–32.

Blanchard, O. J., and P. Diamond (1990): "The Cyclical Behavior of the Gross Flows of U S Workers," *Brookings Papers on Economic Activity*, 0(2), 85–143.

Blanchard, O. J., and C. M. Kahn (1980): "The Solution of Linear Difference Models under Rational Expectations," *Econometrica*, 48(5), 1305–11.

Braun, H., R. De Bock, and R. DiCecio (2006): "Aggregate Shocks and Labor Market Fluctuations," Discussion Paper 004, St Louis Fed Working Paper.

Clark, K. B., and L. H. Summers (1979): "Labor Market Dynamics and Unemployment: A Reconsideration," Discussion paper, Brookings Papers on Economic Activity, Vol. 1, (July 1979).

Cogley, T., and J. M. Nason (1995): "Output Dynamics in Real-Business-Cycle Models," *American Economic Review*, 85(3), 492–511.

Cole, H. L., and R. Rogerson (1999): "Can the Mortensen-Pissarides Matching Model Match the Business-Cycle Facts?," *International Economic Review*, 40(4), 933–59.

Cooley, T. F., and V. Quadrini (1999): "A neoclassical model of the Phillips curve relation," *Journal of Monetary Economics*, 44(2), 165–193.

Davis, S. J., R. J. Faberman, and J. Haltiwanger (2005): "The Flow Approach to Labor Markets: New Data Sources, Micro-Macro Links and the Recent Downturn," Discussion Paper 1639, Institute for the Study of Labor (IZA).

Davis, S. J., and J. Haltiwanger (1999): "On the Driving Forces behind Cyclical Movements in Employment and Job Reallocation," *American Economic Review*, 89(5), 1234–58.

Davis, S. J., J. C. Haltiwanger, and S. Schuh (1996): *Job creation and destruction*. The MIT Press, Boston, MA.

den Haan, W. J., G. Ramey, and J. Watson (2000): "Job Destruction and Propagation of Shocks," *American Economic Review*, 90(3), 482–498.

Faberman, R. J. (2004): "Gross Job Flows over the Past Two Business Cycles: Not all 'Recoveries' are Created Equal," Discussion Paper 372, U.S. Bureau of Labor Statistics.

FISHER, J. D. M. (2006): "The Dynamic Effects of Investment-Specific Technology Shocks," Discussion paper, Forthcoming Journal of Political Economy.

FUJITA, S. (2004): "Vacancy persistence," Federal Reserve Bank of Philadelphia, Working Paper No. 04-23.

GORDON, R. (1989): "The Measurement of Durable Goods Prices," Chicago: University of Chicago Press.

GREENWOOD, J., Z. HERCOWITZ, AND G. W. HUFFMAN (1988): "Investment, Capacity Utilization, and the Real Business Cycle," *American Economic Review*, 78(3), 402–17.

GREENWOOD, J., Z. HERCOWITZ, AND P. KRUSELL (1997): "Long-Run Implications of Investment-Specific Technological Change," *American Economic Review*, 87(3), 342–62.

——— (2000): "The role of investment-specific technological change in the business cycle," *European Economic Review*, 44(1), 91–115.

HALL, R. E. (1995): "Lost Jobs," *Brookings Papers on Economic Activity*, 1995(1), 221–273.

——— (2005): "Employment Fluctuations with Equilibrium Wage Stickiness," *American Economic Review*, 95(1), 50–65.

HANSEN, G. (1985): "Indivisible labor and the business cycle," *Journal of Monetary Economics*, 16, 309–327.

JUSTINIANO, A., AND G. PRIMICERI (2006): "The Time Varying Volatility of Macroeconomic Fluctuations," Discussion paper, Northwestern University.

KEYNES, J. M. (1936): *The General Theory of Employment, Interest, and Money.* Macmillan, London.

KRAUSE, M., AND T. LUBIK (2004a): "A Note on Instability and Indeterminacy in Search and Matching Models," Discussion paper.

——— (2004b): "On-the-Job Search and the Cyclical Dynamics of the Labor Market," Economics Working Paper Archive 513, The Johns Hopkins University,Department of Economics.

——— (2005): "The (Ir)relevance of Real Wage Rigidity in the New Keynesian Model with Search Frictions," *Forthcoming Journal of Monetary Economics*, 0(0), 0–0.

LAGOS, R. (2006): "A Model of TFP," *Forthcoming Review of Economic Studies.*

LAGOS, R., AND N. KIYOTAKI (2006): "A Model of Job and Worker Flows," Discussion paper, New York University.

Lopez-Salido, J. D., and C. Michelacci (2005): “Technology Shocks and Job Flows,” Discussion paper, CEMFI.

Merz, M. (1995): “Search in the Labor Market and the Real Business Cycle,” *Journal of Monetary Economics*, 36(2), 269–300.

Mortensen, D., and E. Nagypal (2005): “More on Unemployment and Vacancy Fluctuations,” Working Paper 11692, NBER.

Mortensen, D. T., and C. A. Pissarides (1994): “Job Creation and Job Destruction in the Theory of Unemployment,” *Review of Economic Studies*, 61(3), 397–415.

Nagypal, E. (2006): “Worker Reallocation over the Business Cycle: The Importance of Job-to-Job Transitions,” Discussion paper, Northwestern University.

Petrongolo, B., and C. A. Pissarides (2001): “Looking into the Black Box: A Survey of the Matching Function,” *Journal of Economic Literature*, 39(2), 390–431.

Polivka, A., and J. Rothgeb (1993): “Overhauling the Current Population Survey: Redesigning the Questionnaire,” *Monthly Labor Review*, 116(9), 10–28.

Rotemberg, J. J. (2003): “Stochastic Technical Progress, Smooth Trends, and Nearly Distinct Business Cycles,” *American Economic Review*, 93(5), 1543–1559.

Rotemberg, J. J., and M. Woodford (1996): “Real-Business-Cycle Models and the Forecastable Movements in Output, Hours, and Consumption,” *American Economic Review*, 86(1), 71–89.

Schmitt-Grohe, S., and M. Uribe (2004): “Solving dynamic general equilibrium models using a second-order approximation to the policy function,” *Journal of Economic Dynamics and Control*, 28(4), 755–775.

Shimer, R. (2005a): “The Cyclical Behavior of Equilibrium Unemployment and Vacancies,” *American Economic Review*, 95(1), 25–49.

——— (2005b): “Reassessing the Ins and Outs of Unemployment,” unpublished manuscript, University of Chicago.

Topel, R. (1990): “Specific capital and unemployment: Measuring the costs and consequences of job loss,” *Carnegie-Rochester Conference Series on Public Policy*, 33, 181–214.

A Job versus Worker Flows Data

The job flows data constructed in Davis, Faberman, and Haltiwanger (2005), capture *employment gains and losses*, where both job creation JCR^{DFH} and destruction JDR^{DFH} are scaled by employment. Worker flows data from the CPS offer an alternative way of representing e.g. employment inflows by scaling the number of workers entering the employment pool by the size of the employment pool. If inflows from non-participation are included, this representation is analogous to the one used in job flows data in the sense that in the same sample the difference between job creation and job destruction or that between CPS inflows and outflows both yield the growth rate of employment g_E:

$$g_E \equiv JCR^{DFH} - JDR^{DFH} \equiv ins^{CPS} - outs^{CPS}.$$

Using the three-pool raw worker flows data from Shimer (2005b) (available for the period 1967:Q2-2004:Q2), I define an ins ratio as the total flows into employment from unemployment (UE_t) and out-of-the-labor-force (IE_t), scaled by the total employment stock:[19]

$$ins_t^{CPS} \equiv \frac{UE_t + IE_t}{E_{t-1}}. \tag{35}$$

The outs ratio is the total flows out of employment to unemployment (EU_t) and out-of-labor-force (EI_t), again scaled by total employment stock:

$$outs_t^{CPS} \equiv \frac{EU_t + EI_t}{E_{t-1}}. \tag{36}$$

Subtracting equation (36) from equation (35), the net change in employment implied by CPS worker flows, $g^W_{E,t}$, is:

$$g^W_{E,t} \equiv \frac{E_t - E_{t-1}}{E_{t-1}} \equiv ins_t^{CPS} - outs_t^{CPS}. \tag{37}$$

The correlation of employment growth calculated from the raw flows as in equation (37) with BLS civilian employment growth is 0.72. Adjusting the gross flows with the means of the factors calculated as in Abowd and Zellner (1985), increases this correlation to 0.77.[20] Table 1 presents the correlation matrix of the business-cycle components of the ins ins^{AZ} and outs $outs^{AZ}$ ratio defined in (35) and (36) where the gross flows were adjusted using the means of the time varying factors calculated as in Abowd and Zellner (1985) from January 1976 to May 1986.

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[19] Scaling by the average of the current and lagged employment stock as opposed to lagged total employment, does not change the results.

[20] The correlation of g_E^W with total non-farm employment growth is 0.71. For the same sample the corresponding correlation of $g_E^{JCR^{DFH},JDR^{DFH}} = JCR_t^{DFH} - JDR_t^{DFH}$ is 0.88. The correlation of $g_E^{JCR^{DFH},JDR^{DFH}}$ with civilian employment is 0.73.

Table 1

Business Cycle Characteristics US Labor Market

	ins^{AZ}	$outs^{AZ}$	JCR^{DFH}	JDR^{DFH}	u	v	y
ins^{AZ}	2.74 [2.16,3.48]	0.26 [0.06,0.46]	0.36 [0.14,0.54]	-0.10 [-0.27,0.09]	0.42 [0.30,0.53]	-0.29 [-0.4,-0.14]	-0.26 [-0.41,-0.12]
$outs^{AZ}$		2.53 [2.16,3.03]	-0.29 [-0.49,-0.07]	0.67 [0.51,0.76]	0.59 [0.47,0.68]	-0.61 [-0.70,-0.46]	-0.64 [-0.74,-0.50]
JCR^{DFH}			4.64 [3.85,5.63]	-0.50 [-0.67,-0.27]	0.01 [-0.23,0.22]	0.03 [-0.20,0.28]	0.10 [-0.17,0.39]
JDR^{DFH}				7.68 [6.69,8,93]	0.48 [0.30,0.61]	-0.58 [-0.71,-0.42]	-0.61 [-0.75,-0.43]
u					7.13 [6.22,8.21]	-0.95 [-0.97,-0.92]	-0.87 [-0.91,-0.81]
v						8.56 [7.90,9.49]	0.91 [0.86,0.95]
y							1.00 [NA]

Note: Correlations Matrix of Business-Cycle Component of the Ins and Outs to Employment and Job Creation and Destruction Series, 1967Q2-2004Q2. Standard deviations (relative to output) are shown on the diagonal. All series were logged and detrended using a HP filter with weight 1600. Block-bootstrapped ninety-five percent confidence intervals in brackets. See the appendix for data sources or worker and job flow series; y is real chain weighted level of output per capita, u the civilian unemployment rate (16 yrs +), and v the index of help-wanted advertising in newspapers scaled by the labor force.

Table 2

Model Parametrization

Parameter	Value	Interpretation	Source
β	$(1.03)^{-1/4}$	Discount factor	Annual interest rate of about 3%
σ	1	Coefficient of relative risk aversion	
α	.36	Factor share	US Data
δ	0.025	Depreciation rate	US Data
		Labor Market Variables	
u	0.11	Unemployment Rate	US data (CPS)
ξ	0.70	Elasticity of matching function w.r.t. u	Data
ρ	0.10	Total job separation	US data (CPS)
ρ_n	0.018	Endogenous job separation	US data (PSID)
ρ_x	0.0835	Exogenous job separation	US data (CPS)
$q(\theta)$	0.71	Job-filling rate	US data
$m(\theta)$	0.80	Job-finding rate	Calibration
μ		Efficiency parameter	Calibration
η	0.5	Bargaining Power of worker	

Table 3

Impact and Total Magnification

Magnification	Indivisible Labor		Search Model	
	Neut	Inv	Neut	Inv
Impact	1.86	0.73	1.11	0
Total	5.74	3.00	5.25	2.27

Note: See text for definitions. Model statistics are averages over 100 simulations of 200 periods.

Table 4

Beveridge Curve

corr(u_t, v_{t+k})	3	2	1	0	-1	-2	-3
US data	-0.61	-0.80	-0.93	-0.95	-0.81	-0.61	-0.37
Search Model with Neutral Shocks	-0.36	-0.38	-0.50	-0.62	-0.07	-0.11	-0.14
Search Model with Inv Shocks	-0.84	-0.87	-0.84	-0.72	-0.53	-0.33	-0.16

Note: Data sample: 1967:Q2-2004Q2. All series were logged and detrended with a Hodrick Prescott (1600) Filter. Model statistics are averages over 100 simulations of 200 periods.

Table 5

Autocorrelation Function of Vacancy Series

Lags	1	2	3	4
US data (HWI)	0.92	0.75	0.53	0.30
Search Model with Neutral Shocks	0.06	0.02	-0.04	-0.07
Search Model with Inv Shocks	0.89	0.70	0.52	0.35

Note: Data sample: 1967:Q2-2004Q2. All series were logged and detrended with a Hodrick Prescott (1600) Filter. Model statistics are averages over 100 simulations of 200 periods.

Table 6

Comparison of Business Cycle Statistics US and Model Data

	Data	Indivisible Labor			Search Model	
		Neut	Inv		Neut	Inv
σ_y	1.57	1.79	0.67		1.21	0.10
σ_C	0.74	0.47	0.42		0.44	0.51
σ_I	5.87	5.51	3.44		3.26	1.23
$\sigma_{Y/N}$	0.85	0.47	0.42		0.90	0.07
$\sigma_{ins^{AZ}}$	4.30			σ_{ins}	2.83	0.18
$\sigma_{outs^{AZ}}$	3.97			σ_{outs}	2.25	0.17
$\sigma_{JCR^{DFH}}$	7.45			$\sigma_{jcr^{NET}}$	16.66	1.11
$\sigma_{JDR^{DFH}}$	11.47			$\sigma_{jdr^{NET}}$	12.57	1.03
σ_U	11.63				3.06	0.24
σ_V	13.53				2.86	0.13

Note: Standard deviations in percent. Data sample: 1967:Q2-2004Q2. The variable y is real chain weighted level of output per capita. C is real consumption on nondurables and services and government per capita. I is real consumption of durables and private investment per capital. Labor productivity is y over per capita hours worked. All series are logged and detrended with a Hodrick Prescott (1600) Filter. Model statistics are averages over 100 simulations of 200 periods.

Table 7

Robustness to Alternative Calibrations

	Baseline	$u = 0.06$	$\eta = 0.15$	$\rho_x = 0.099$
σ_y	0.10	0.08	0.14	0.08
$\sigma_{ins}, \sigma_{jcr}$	0.18	0.10	0.41	0.03
$\sigma_{outs}, \sigma_{jdr}$	0.17	0.09	0.32	0.02
σ_U	0.24	0.15	0.49	0.09
σ_V	0.13	0.08	0.54	0.20
$corr(V_t, V_{t-1})$	0.89	0.95	0.71	0.95
$corr(V_t, U_t)$	-0.72	-0.96	-0.53	-0.98

Note: All series are logged and detrended with a Hodrick Prescott (1600) Filter. Model statistics are averages over 100 simulations of 200 periods.

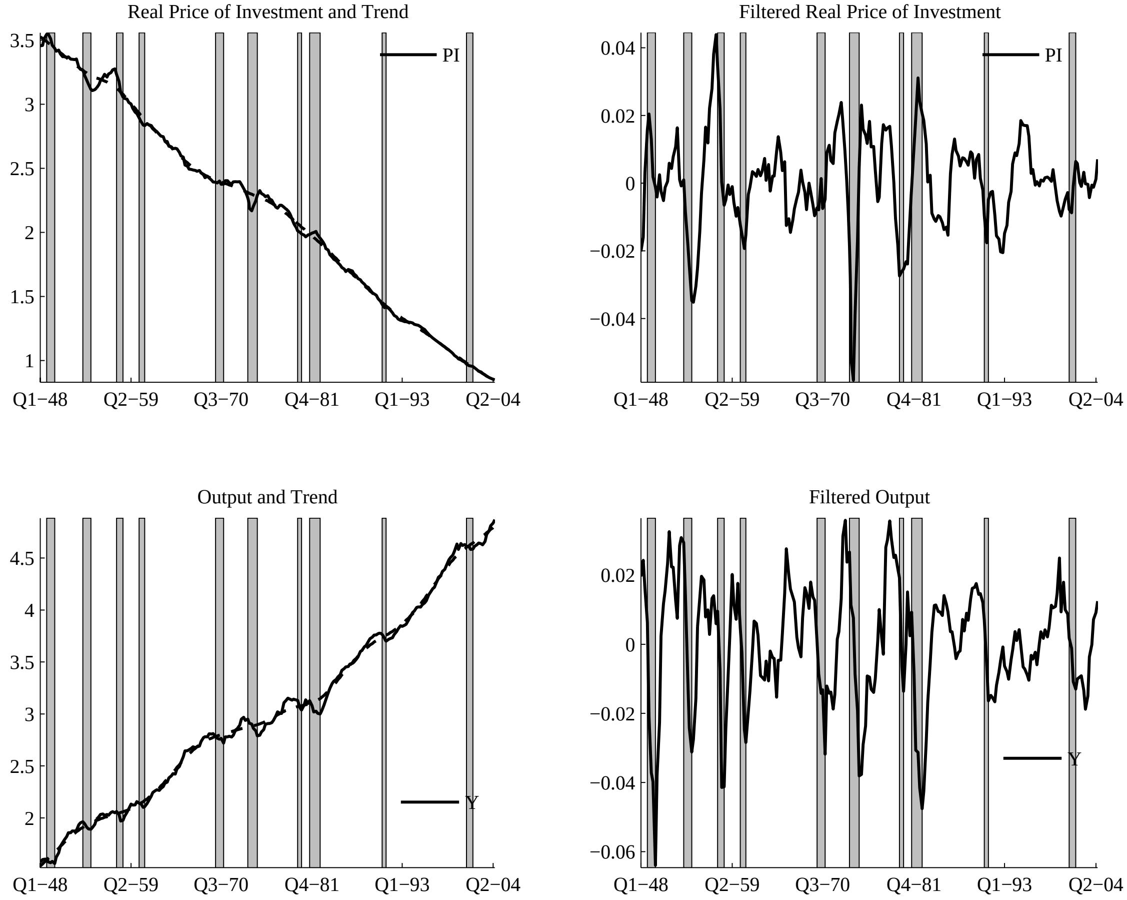

Figure 1

Real Investment Price and Output: Trend and Cyclical Component 1948:I-2001:IV. Real investment price is price of investment relative to price of consumption. Output is real chain weighted level of output per capita.

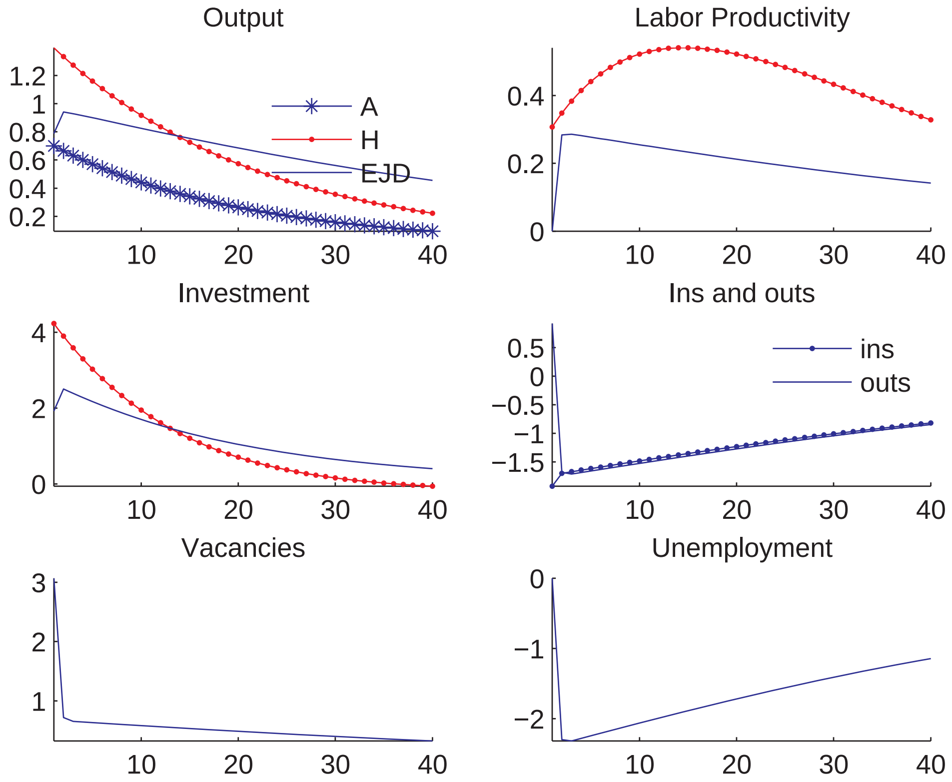

Figure 2
Impulse Responses in percentage deviations to a one standard deviation neutral technology shock A. H corresponds to the indivisible labor model, EJD to the search model.

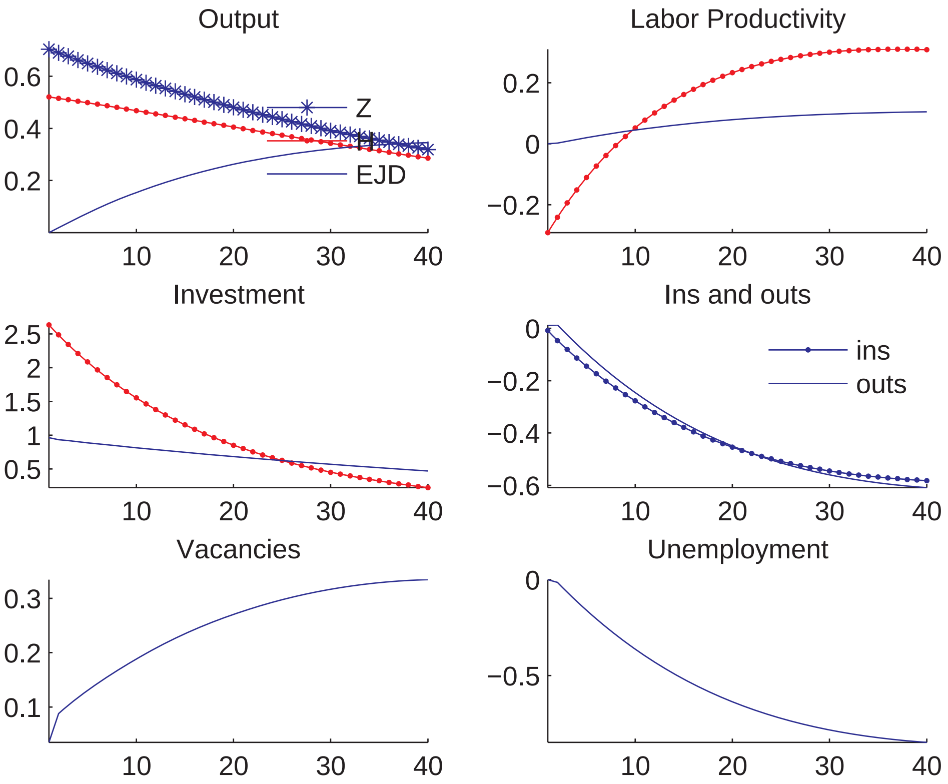

Figure 3

Impulse Responses in percentage deviations to a one standard deviation positive investment-specific technology shock Z. H corresponds to the indivisible labor model, EJD to the search model.

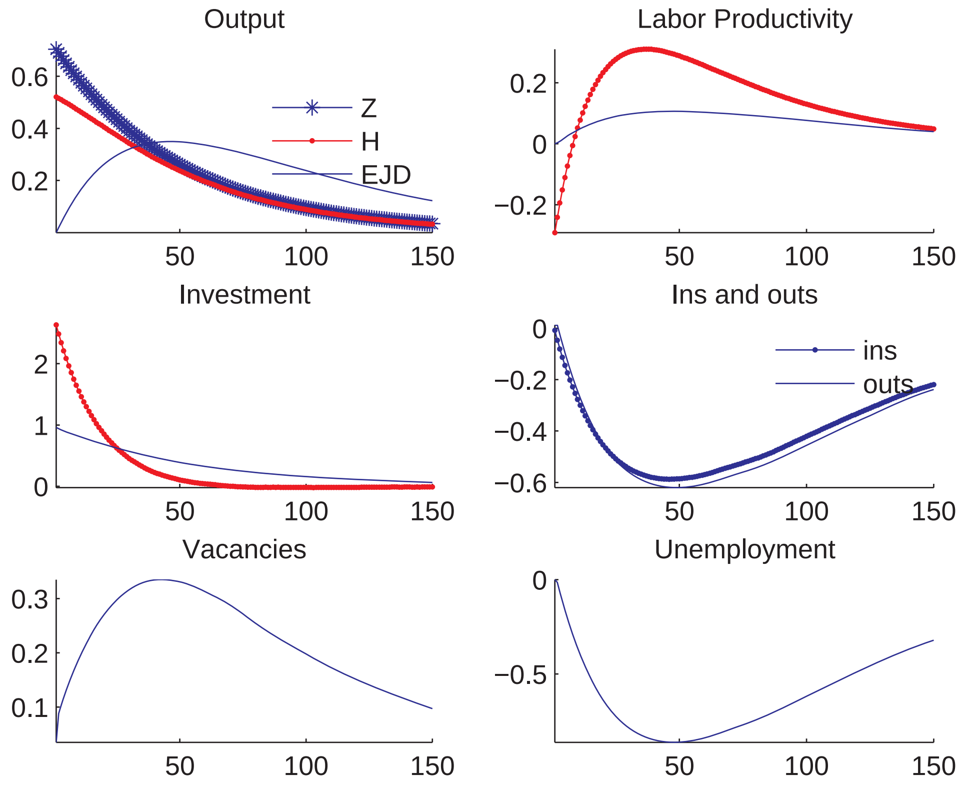

Figure 4
Impulse Responses in percentage deviations to a one standard deviation positive investment-specific technology shock Z 200 quarters out. H corresponds to the indivisible labor model, EJD to the search model.

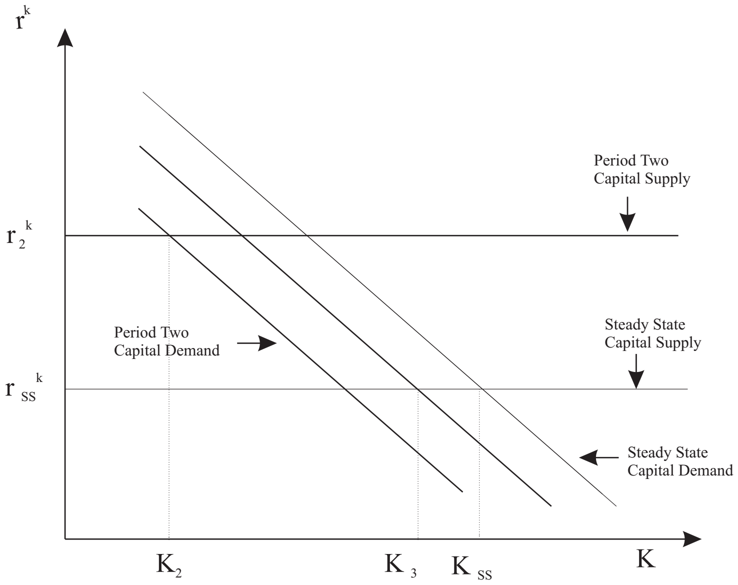

Figure 5
Capital Market Equilibrium Following One-Time Investment-Specific Technology Shock.

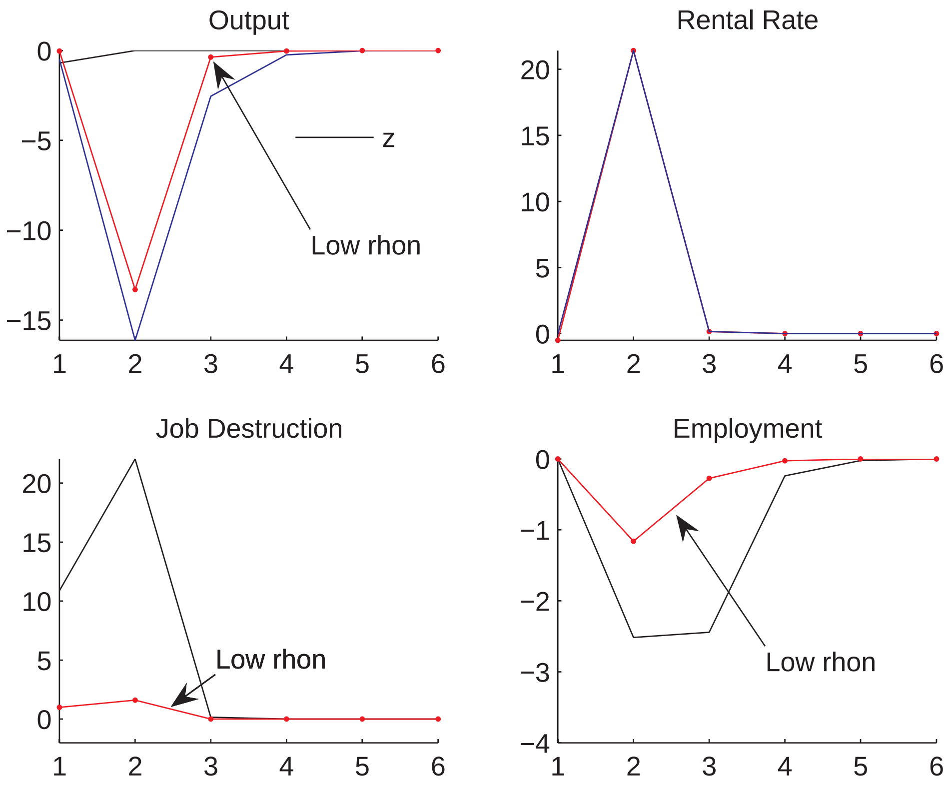

Figure 6

Impulse Responses in percentage deviations to a one-time positive investment-specific technology shock with no persistence. Risk aversion is set at $\sigma = 0.00001$. Benchmark value for the exogenous job separation rate ρ_x is 0.0835 (with total job separation 0.10). Low rhon corresponds to an exogenous job destruction component of ρ_x= 0.099.

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