

# Job Destruction and Propagation of Shocks

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*This paper considers propagation of aggregate shocks in a dynamic general-equilibrium model with labor-market matching and endogenous job destruction. Cyclical fluctuations in the job-destruction rate magnify the output effects of shocks, as well as making them much more persistent. Interactions between capital adjustment and the job-destruction rate play an important role in generating persistence. Propagation effects are shown to be quantitatively substantial when the model is calibrated using job-flow data. Incorporating costly capital adjustment leads to significantly greater propagation. (JEL E24, E32)*

It has been well documented that the cyclical adjustment of labor input chiefly represents movement of workers into and out of employment, rather than adjustment of hours at given jobs. Thus, in understanding business cycles, it is centrally important to understand the formation and breakdown of employment relationships. The nature of employment adjustments over the cycle has also received close scrutiny. Evidence from a number of sources indicates that recessionary employment reductions are accounted for by elimination of preexisting jobs, i.e., job destruction, to a greater extent than by diminished creation of new jobs. Substantial cyclical variation in the rate of job destruction suggests that closer consideration of the breakdown of employment relationships may help to explain how shocks to the economy generate large and persistent output fluctuations.<sup>1</sup>

This paper addresses these issues by studying the endogenous breakup of employment relationships in a dynamic general-equilibrium model

with labor-market matching. Production is assumed to entail long-term relationships between workers and firms. We consider a version of Dale T. Mortensen and Christopher A. Pissarides' (1994) model, wherein a worker and firm who are currently matched must decide each period whether to preserve or sever their relationship, based on their current-period productivity. By altering the trade-off between match preservation and severance, aggregate productivity shocks induce fluctuations in the job-destruction rate, thereby exerting effects on output that go beyond those resulting from productivity variations in continuing relationships. We embed the basic Mortensen-Pissarides mechanism into a full dynamic general-equilibrium model, analyze the role of fluctuations in the job-destruction rate in propagating shocks, and assess the model's quantitative implications.

Most business-cycle models in the real-business-cycle (RBC) tradition share the feature that model-generated output data exhibit dynamic characteristics nearly identical to those of the underlying exogenous shocks, so that economic mechanisms play a minimal role in propagating shocks (Timothy Cogley and James M. Nason, 1993, 1995; Julio J. Rotemberg and Michael Woodford, 1996). In our model, however, fluctuations in the job-destruction rate give rise to a significant propagation mechanism: productivity shocks are magnified in their effect on output at the point of impact, and the persistence of output effects is greatly increased. Using simulated data from a calibrated version of the model, we find that the standard deviation of output is roughly two and one-half times larger than the standard deviation of the

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<sup>1</sup> For evidence on the importance of employment adjustment relative to hours adjustment, see David M. Lilien and Robert E. Hall (1986). Evidence on recessionary worker flows is provided by Olivier Jean Blanchard and Peter Diamond (1990), while Steven J. Davis and John C. Haltiwanger (1992) consider job flows in manufacturing.

underlying driving process, reflecting both impact magnification and persistence. By way of comparison, the standard RBC model, as well as Gary D. Hansen's (1985) indivisible labor variant, yield magnification ratios of less than two; further, nearly all of the magnification in the latter models occurs on impact, meaning that the models generate only slight amounts of persistence. We further verify that the simulated data yield autocorrelations of output growth rates that match well the autocorrelations observed in U.S. data, reflecting the large amount of persistence generated by the model.

Interactions between capital adjustment and job destruction play an important role in our propagation mechanism. A negative productivity shock generates a spike in job destruction, and employment remains persistently lower on account of matching frictions. Lower employment reduces the demand for capital, leading to a lower supply of capital in future periods. The productivity shock thereby reduces the equilibrium capital stock, magnifying the future output effects of the shock. Importantly, this capital-adjustment effect is distinct from consumption-smoothing behavior on the part of households. When consumption smoothing is considered, the power of the propagation mechanism is greatly increased, as lower household investment following the shock leads to further reductions in the equilibrium capital stock, increases in the capital rental rate, and persistently higher rates of job destruction and lower levels of output. To verify that interactions between capital adjustment and job destruction play a central role, we show that propagation effects are much reduced if either capital-stock adjustments or fluctuations in the job-destruction rate are suppressed. Further, we demonstrate that propagation effects are significantly greater when the model is extended to introduce costs of adjusting capital across firms.

Several recent papers have considered labor-market search and matching within a quantitative context. Monika Merz (1995) and David Andolfatto (1996) have implemented labor-market matching models in the spirit of Pissarides (1985), where all job destruction is exogenous and the separation rates are constant over time. These papers demonstrate that incorporating matching improves the ability of the RBC framework to explain macroeconomic facts, including low variability of wages and productivity, and persistence of unemployment

movements. Using our labor-market measurements, however, we find that the implied propagation mechanism is much weaker when the job-destruction rate is fixed, and further, models in this vein cannot account for the cyclical patterns of job creation and destruction. More recently, Harold L. Cole and Richard Rogerson (1996) have shown that a reduced-form model inspired by Mortensen and Pissarides can do a good job explaining statistical regularities in the Longitudinal Research Database (LRD), while Joao Gomes et al. (1997) have studied the ability of a simple search model incorporating endogenous separation to account for cyclical variability of the unemployment rate, the duration of unemployment spells, and flows into and out of unemployment.<sup>2</sup>

Our paper features some methodological advances relative to previous literature. We compute the job-destruction rate as a fixed point within a dynamic general equilibrium exhibiting heterogeneity on the production side. Importantly, we do not rely on social planner solutions that restrict model parameters, in contrast to Merz (1995) and Andolfatto (1996). Further, we utilize a new specification of the labor-market matching function that is motivated by search-theoretic considerations.

Section I describes the theoretical model, Section II describes the propagation mechanism using a simplified specification, and a quantitative assessment using the full model is conducted in Section III. Section IV shows that the propagation mechanism is significantly strengthened when capital-adjustment costs are introduced, and Section V concludes.

## I. Model

### A. Employment Relationships

Employment relationships are taken to consist of two agents, a worker and a firm, that engage in production through discrete time until the relationship is severed. Individual employment relationships are indicated by subscript  $i$ . In each period  $t$ , firm  $i$  hires capital, denoted  $k_{it}$ . Output from production is given by  $z_t a_{it} k_{it}^\alpha$ ,

<sup>2</sup> While they consider a different class of models, Cogley and Nason (1995) and Craig Burnside and Martin Eichenbaum (1996) also emphasize that imperfections in the adjustment of labor input can play a role in propagating business-cycle shocks.

where  $z_t$  represents a random aggregate productivity disturbance, and  $a_{it}$  gives a random disturbance that is specific to relationship  $i$ . We assume that the relationship might be severed for exogenous reasons in any given period, in which case production does not take place. Let  $\rho^x$  indicate the probability of exogenous separation, assumed to be independent of  $z_t$  and  $a_{it}$  and of shocks realized in other relationships. The firm selects  $k_{it}$  after observing  $z_t$ ,  $a_{it}$ , and whether or not exogenous separation has occurred. Thus, capital may be freely adjusted in response to any shocks, either aggregate or idiosyncratic.<sup>3</sup>

After observing all the shocks in period  $t$ , the worker and firm may choose to separate endogenously. If either exogenous or endogenous separation occurs, then there is no production in period  $t$ . In this event, the worker obtains a payoff of  $b + w_{it}$  based on opportunities outside of the current relationship, where  $b$  indicates the worker's benefit obtained in the current period from being unemployed, and  $w_{it}$  denotes the expected present value of the worker's payoffs obtained in future periods. We take  $b$  to be exogenous. Due to free entry of firms into the worker-firm matching process, as described in the following subsection, the firm obtains a payoff of zero outside of the relationship.<sup>4</sup>

Consider now the separation decision of the worker and firm. If the relationship is not severed, then production occurs and the worker and firm obtain the following joint payoff:

$$(1) \quad \max_{k_{it}} [z_t a_{it} k_{it}^\alpha - r_t k_{it}] + g_{it},$$

where  $r_t$  is the rental rate of capital, and  $g_{it}$  gives the expected current value of future joint payoffs obtained from continuing the relation-

ship into the following period.<sup>5</sup> Given any contingency that arises, the worker and firm bargain over the division of their maximized joint surplus. Negotiation is resolved according to the Nash bargaining solution, where  $\pi$  is the firm's bargaining weight. In particular, after observing productivity information, the worker and firm will choose whether or not to sever their relationship based on which option maximizes their joint payoff. Since the current-period payoff becomes less attractive as  $a_{it}$  declines, it follows that there exists a level  $\underline{a}_{it}$  such that the partners will opt for separation if  $a_{it} < \underline{a}_{it}$ , while the match will be preserved and production will occur if  $a_{it} \geq \underline{a}_{it}$ . The level of  $\underline{a}_{it}$ , referred to as the *job-destruction margin*, is determined as follows:

$$(2) \quad \max_{k_{it}} [z_t \underline{a}_{it} k_{it}^\alpha - r_t k_{it}] + g_{it} = b + w_{it},$$

where it should be recalled that the value of the firm's outside opportunities is zero. Associated with  $\underline{a}_{it}$  is the *endogenous separation rate*  $\rho_{it}^n$ :

$$(3) \quad \rho_{it}^n = \int_{-\infty}^{\underline{a}_{it}} d\mu(a_{it}),$$

where  $\mu$  is the probability distribution over  $a_{it}$ . The endogenous separation rate expresses the probability that a worker-firm match surviving the exogenous separation shock chooses to sever the relationship, based on its idiosyncratic productivity shock. Correspondingly, the overall separation rate is given by  $\rho^x + (1 - \rho^x)\rho_{it}^n$ .

## B. Matching Market

Employment relationships are formed in a matching market. There is a continuum of workers in the economy, having unit mass, along with a continuum of potential firms, having infinite mass. Let  $U_t$  denote the mass of unmatched workers seeking employment in period  $t$ , and let  $V_t$  denote the mass of firms that post vacancies. The matching process within a period takes place at the same time as production for that period, and workers and firms

<sup>3</sup> In Section IV we consider the alternative possibility that capital adjustment is costly, in the sense that  $k_{it}$  must be chosen before  $a_{it}$  and the exogenous separation shock are observed.

<sup>4</sup> The assumption that the idiosyncratic productivity shocks  $a_{it}$  are independently and identically distributed over time greatly simplifies the analysis of the model, as it eliminates the need to consider match-specific state variables for continuing relationships. In Section III, subsection D, we consider the robustness of our propagation results to the addition of a persistent component to the process of idiosyncratic shocks.

<sup>5</sup> Observe that in (1) the firm chooses capital to maximize the joint returns of the worker and firm. In essence, the worker and firm are able to contract efficiently over the choice of capital.

whose matches are severed can enter their respective matching pools and be rematched within the same period. All separated workers are assumed to reenter the unemployment pool; i.e., we abstract from workers' labor-force participation decisions. Firms may choose whether or not to post vacancies, where posting entails a cost of  $c$  per period. Free entry by firms determines the size of the vacancy pool.

Workers and firms that are matched in period  $t$  begin active employment relationships, as described in the preceding subsection, at the start of period  $t + 1$ , while unmatched workers remain in the worker matching pool. The flow of successful matches within a period is given by the following matching function:

$$(4) \quad m(U_t, V_t) = \frac{U_t V_t}{(U_t^{\lambda} + V_t^{\lambda})^{1/\lambda}}.$$

In choosing this matching function, we depart from the standard Cobb-Douglas specification that has been used in the previous literature. Our new specification is motivated by considering how the matching technology operates on individual workers and firms. Imagine that  $J_t$  channels are set up to carry out matching within a given period. Each worker is assigned randomly to one of the channels, as is each firm. Agents assigned to the same channel are successfully matched, while the remaining agents are unmatched. With this procedure, a worker locates a firm with probability  $V_t/J_t$ , a firm locates a worker with probability  $U_t/J_t$ , and the total mass of matches is  $U_t V_t/J_t$ .

The number of channels  $J_t$  depends on the sizes of the unemployment and vacancy pools, reflecting thin market externalities. In particular, we adopt the specification  $J_t = (U_t^{\lambda} + V_t^{\lambda})^{1/\lambda}$ , from which we obtain (4). Observe that the matching function is increasing in its arguments and satisfies constant returns to scale.<sup>6</sup>

<sup>6</sup> A major advantage of our new matching function, relative to the Cobb-Douglas specification, is that the new function guarantees matching probabilities between zero and one for all  $U_t$  and  $V_t$ . In applying the Cobb-Douglas specification, truncation is necessary to rule out matching probabilities greater than unity. Such truncation can give rise to discontinuities that complicate obtaining numerical solutions to the model.

### C. Household Behavior

We assume that workers pool their incomes at the end of the period and choose aggregate consumption to maximize the expected-utility function of a representative worker, given by:

$$(5) \quad E_t \left[ \sum_{s=t}^{\infty} \beta^{s-t} \frac{C_s^{1-\gamma} - 1}{1-\gamma} \right],$$

where  $\beta$  gives the discount factor, and  $C_s$  indicates aggregate consumption in period  $s$ .<sup>7</sup> Symmetry in consumption together with independence over time in the match-specific productivity shocks  $a_{it}$  allows us to suppress the  $i$  subscripts for the remainder of the paper. Aggregate wage and profit income obtained by the household may be written:

$$I_t = (1 - \rho^x) N_t$$

$$\times \int_{a_t}^{\infty} [z_t a_t (k_t^*)^{\alpha} - r_t k_t^*] d\mu(a_t) - c V_t,$$

where  $N_t$  indicates the mass of employment relationships at the beginning of period  $t$ , and  $k_t^*$  denotes the capital level chosen by individual firms in period  $t$ , which solves (1). Note that  $k_t^*$  is a function of  $a_t$ . The household wealth constraint is given by:

$$(6) \quad C_t + K_{t+1} = I_t + B_t + (r_t + 1 - \delta) K_t,$$

where  $K_t$  is the aggregate capital stock at the beginning of period  $t$ . We interpret  $b$  as non-tradable units of the consumption good that are produced at home by unemployed workers, so

<sup>7</sup> The income-pooling assumption and corresponding implications for endogenous separation decisions can be supported most directly by assuming that the utility function of individual firms and workers is given by  $E_t[\sum_{s=t}^{\infty} \beta^{s-t} C_s^{-\gamma} y_s]$ , where  $y_s$  is the amount of consumption good obtained by the firm or worker. To obtain exact aggregation more generally, a set of assets that spans the space of idiosyncratic shocks, but does not condition payments on employment status, may be needed. Note, however, that only a few assets, such as bonds or capital, might be sufficient to effectively smooth consumption against uninsurable idiosyncratic shocks; see, for example, Deborah J. Lucas (1994).

that aggregate home-produced output is  $B_t = bU_t$ .<sup>8</sup> Finally,  $\delta$  denotes the depreciation rate.

#### D. Equilibrium

Equilibrium values of  $w_t$  and  $g_t$  are determined as follows. Consider first the situation facing a worker and firm that are matched at the start of period  $t + 1$ . If their relationship is severed in period  $t + 1$ , then they obtain a joint payoff of  $b + w_{t+1}$ . If they avoid severance, then their relationship generates a surplus net of the worker's outside payoff, which may be written as follows:

$$(7) \quad s_{t+1} = z_{t+1}a_{t+1}(k_{t+1}^*)^\alpha - r_{t+1}k_{t+1}^* + g_{t+1} - (b + w_{t+1}).$$

The worker and firm bargain over this surplus, obtaining shares  $1 - \pi$  and  $\pi$ , respectively. Division of the surplus is accomplished via transfer payments; e.g., the firm makes a wage payment to the worker.

Next, consider the situation of a worker in the period  $t$  unemployment pool. The worker obtains future payoffs of  $b + w_{t+1}$  if he does not succeed in being matched in period  $t$ , or if he is successfully matched in period  $t$ , but the match is severed prior to production in period  $t + 1$ . Alternatively, the worker receives a share of surplus from a productive relationship in period  $t + 1$ , and thus obtains future payoffs of  $(1 - \pi)s_{t+1} + b + w_{t+1}$ , if he is matched in period  $t$  and the match survives in period  $t + 1$ . The worker's expected future payoffs, appropriately discounted, may therefore be written:

$$(8) \quad w_t = E_t \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\gamma} \left( \lambda_t^w (1 - \rho^x) \times \int_{a_{t+1}}^{\infty} (1 - \pi)s_{t+1} d\mu(a_{t+1}) + b + w_{t+1} \right) \right],$$

<sup>8</sup> Home production in standard RBC settings has been considered by Jess Benhabib et al. (1991) and Jeremy Greenwood and Zvi Hercowitz (1991). In contrast to these papers, our results do not rely on stochastic variability of the home-production technology.

where  $\lambda_t^w = m(U_t, V_t)/U_t$  indicates the probability that the worker is successfully matched. Observe in (8) that the worker obtains  $(1 - \pi)s_{t+1}$  with probability  $\lambda_t^w(1 - \rho^x)(1 - \rho_{t+1}^n)$ , reflecting the event that the worker is matched in period  $t$  and the match survives in period  $t + 1$ .

A firm in the period  $t$  vacancy pool, in contrast, must obtain a payoff of zero as a consequence of free entry. In particular, we have:

$$(9) \quad 0 = -c + \lambda_t^f E_t \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\gamma} (1 - \rho^x) \times \int_{a_{t+1}}^{\infty} \pi s_{t+1} d\mu(a_{t+1}) \right],$$

where  $\lambda_t^f = m(U_t, V_t)/V_t$  gives the firm's matching probability.<sup>9</sup> Finally, the expected future joint returns of a worker and firm that remain matched in period  $t$  are:

$$(10) \quad g_t = E_t \left[ \beta \left( \frac{C_{t+1}}{C_t} \right)^{-\gamma} \left( (1 - \rho^x) \times \int_{a_{t+1}}^{\infty} s_{t+1} d\mu(a_{t+1}) + b + w_{t+1} \right) \right].$$

In contrast to (8) and (9), the partners in a continuing relationship do not need to be matched, so that they obtain the surplus  $s_{t+1}$  with probability  $(1 - \rho^x)(1 - \rho_{t+1}^n)$ .

Equilibrium in the capital market is determined as follows. The equilibrium value of  $r_t$  is determined by the following market-clearing condition:

$$(11) \quad N_t(1 - \rho^x) \int_{a_t}^{\infty} k_t^* d\mu(a_t) = K_t.$$

<sup>9</sup> If the conditional expectation term in (9) lies below  $c$  at every level of  $V_t$ , then no firm would wish to post a vacancy, and (9) would be replaced by  $V_t = 0$ .



The left-hand side of (11) indicates the demand for capital, consisting of the total number of employment relationships at the start of period  $t$ ,  $N_t$ , times the expected capital selection for each relationship. The capital market clears when capital demand is equal to the supply of capital in period  $t$ , given by  $K_t$ . In turn,  $K_{t+1}$  is determined by maximization of (5) subject to (6), for which the following is sufficient:

$$(12) \quad C_t^{-\gamma} = \beta E_t[C_{t+1}^{-\gamma}(r_{t+1} + 1 - \delta)].$$

Finally, the number of relationships and the number of unemployed workers are determined by:

$$(13) \quad N_{t+1} = (1 - \rho^x)(1 - \rho_t^n)N_t + m(U_t, V_t),$$

$$(14) \quad U_t = 1 - (1 - \rho^x)(1 - \rho_t^n)N_t.$$

Observe from (14) that workers separating from their employment relationships in period  $t$  enter the period  $t$  worker matching pool.

## II. Propagation Mechanism

The interaction between capital adjustment and the job-destruction rate in our model, mediated by the rental rate of capital, serves to magnify the output effects of aggregate productivity shocks and make them more persistent. In this section we illustrate the workings of this propagation mechanism using a simple conceptual experiment. The economy is assumed to begin in a steady-state equilibrium, with a constant level  $z$  of the aggregate productivity parameter. In period 1, the economy is hit with a one-time surprise productivity shock  $z_1 < z$ . Aggregate productivity then returns to  $z_t = z$  for all  $t > 1$ . We consider how this one-time productivity shock affects the rental rate, job-destruction rate, and aggregate output for various specifications of the model.

### A. Linear Utility

First consider the case  $\gamma = 0$ , in which household utility is linear in consumption. Since the economy follows a perfect-foresight path fol-

lowing the initial productivity shock, we have  $r_t = 1/\beta - (1 - \delta)$  for all  $t > 1$ . The equilibrium has a particularly simple form in this case, as indicated in the following lemma. We omit the proof for brevity.<sup>10</sup>

**LEMMA 1:** *In the linear utility case, a one-time productivity shock in period 1 implies that  $g_t - w_t$  remains constant at its steady-state value for all  $t \geq 1$ .*

The intuition behind Lemma 1 is as follows. The payoffs of individual employment relationships depend on capital- and labor-market conditions only through  $r_t$  and  $\lambda_t^w$ . Since  $r_t$  remains constant at its steady-state value following period 1, while  $\lambda_t^w$  also remains constant due to constant returns to scale in the matching function, it follows that the future surplus  $g_t - w_t$  does not change.

Using Lemma 1, it can be verified that the one-time productivity shock must lead to a spike in job destruction in period 1.

**PROPOSITION 1:** *In the linear utility case, a one-time productivity shock implies  $\rho_1^n > \rho^n$  and  $\rho_t^n = \rho^n$  for  $t > 1$ , where  $\rho^n$  gives the endogenous separation rate in the initial steady state.*

**PROOF:**

Let  $\psi$  denote the steady-state value of  $g_t - w_t$ . Solving for the profit-maximizing selection  $k_1^*$ , plugging it into (2), and rearranging gives:

$$z_1 \left( \frac{z_1}{r_1} \right)^{\alpha/(1-\alpha)} \underline{a}_1^{1/(1-\alpha)} (\alpha^{\alpha/(1-\alpha)} - \alpha^{1/(1-\alpha)}) + \psi = b.$$

Suppose  $\underline{a}_1 \leq \underline{a}$  (where unsubscripted variables denote steady-state values). Since  $z_1 < z$ , we have  $z_1/r_1 > z/r$ , as the steady-state values must also satisfy (2).

Let capital demand be denoted by  $K_1^D$ . Substituting the solution for  $k_1^*$  into the left-hand side of (11) gives:

<sup>10</sup> The proof is available from the authors upon request.

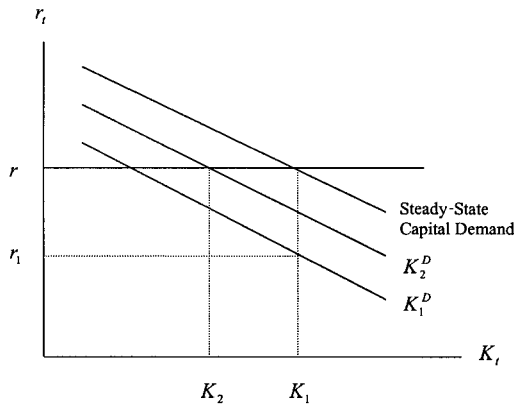


FIGURE 1. CAPITAL-MARKET EQUILIBRIUM WITH ONE-TIME PRODUCTIVITY SHOCK

$$K_1^D = N(1 - \rho^x) \int_{a_1}^{\infty} \left( \frac{z_1 a_1 \alpha}{r_1} \right)^{1/(1-\alpha)} d\mu(a_t).$$

Thus,  $K_1^D > K$  is implied, where  $N$  and  $K$  are predetermined at their steady-state values. Since this violates capital-market clearing in period 1, we conclude  $a_1 > a$ , and thus  $\rho_1^n > \rho^n$ . The claim that  $\rho_t^n = \rho^n$  for  $t > 1$  follows directly from (2), using  $z_t = z$ ,  $r_t = 1/\beta - (1 - \delta)$ , and  $g_t - w_t = \psi$  for  $t > 1$ .

As the proof demonstrates, it is possible for the job-destruction rate to fall following the negative productivity shock only if the rental rate falls farther than does the productivity parameter. But if both the rental rate and the job-destruction margin  $a_1$  are reduced by the shock, then capital demand becomes too high to clear the capital market. It follows that  $\rho_1^n$  must rise. Further, since the rental rate returns to its steady-state level following period 1, the endogenous destruction rate returns to its steady state also.

The spike in job destruction implies that aggregate employment will be lower in periods following the shock, which will also reduce the demand for capital. The associated capital adjustment is illustrated in Figure 1. From the left-hand side of (11) it may be seen that capital demand will be lower if either  $z_t$  or  $N_t$  is reduced. Thus, the lower value of  $z_1$  leads to a downward shift in the period 1 capital-demand curve, labeled  $K_1^D$ , relative to the capital-

demand curve in the steady state. Correspondingly, the rental rate falls to  $r_1$ , since the capital stock is predetermined at its steady level, but job destruction still rises since the productivity effect dominates. In period 2, the productivity parameter returns to its steady-state level, but since  $N_2 < N_1$  the capital-demand curve increases only to  $K_2^D$ , remaining below the steady-state curve. Thus, the capital market clears at a level  $K_2$  lying below the steady-state capital stock. Further, the capital stock will remain below its steady-state level as employment returns to the steady state. It follows that the productivity shock is propagated to the capital market through its effect on employment.

### B. Fixed Capital

To highlight the role of capital adjustment, we contrast the preceding case with a specification in which capital is fixed at its steady-state value, while the utility function remains linear. Since the supply of capital cannot adjust, while capital demand is reduced due to lower employment, it follows that  $r_t$  must be lowered for each  $t$  to clear the capital market. The resulting paths of the rental rate, endogenous separation rate, and output are compared in Figures 2A–C, which depict numerically computed equilibrium paths for a particular parameterization of the model.<sup>11</sup> Figure 2A indicates paths of the rental rate; observe that  $r_t < r$  for  $t > 1$  in the fixed-capital case. Since future rental rates are lower, the endogenous separation rate actually falls below its steady-state level following period 1, as seen in Figure 2B. The implied output effects are shown in Figure 2C: the absence of capital adjustment, together with the lower endogenous separation rate, significantly attenuate the output reduction following the shock, relative to the flexible-capital case. In Figure 2C it is also shown that the job-destruction spike magnifies the output effect of the shock in period 1, relative to a case in which all separations are exogenous (i.e., the endogenous destruction rate is held fixed at its steady-state value).

We conclude that the importance of job de-

<sup>11</sup> Here the depreciation rate is set to  $\delta = 0.5$  in order to produce clear illustrations; a more realistic value is used in the empirical-evaluation section. We also set  $z = 1$  and  $z_1 = 0.935$ . Values of  $\alpha$ ,  $\gamma$ ,  $\beta$ ,  $\pi$ ,  $\rho^x$ ,  $l$ ,  $b$ ,  $c$ , and  $\sigma_a$  are as indicated in Table 1.

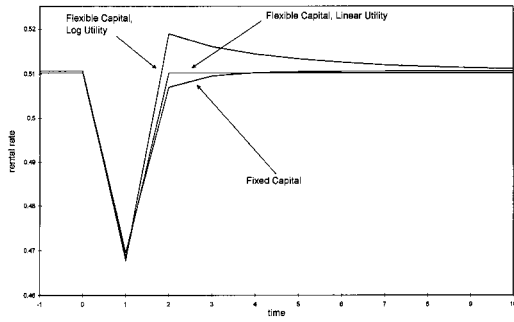


FIGURE 2A. EFFECT OF ONE-TIME NEGATIVE PRODUCTIVITY SHOCK ON RENTAL RATE

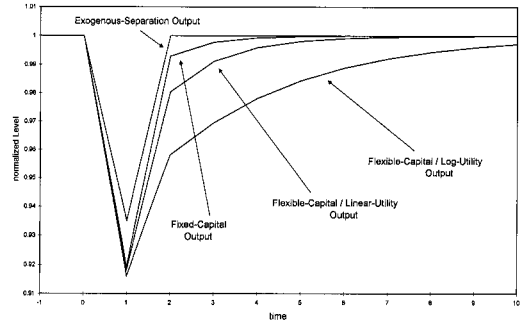


FIGURE 2C. EFFECT OF ONE-TIME NEGATIVE PRODUCTIVITY SHOCK ON OUTPUT

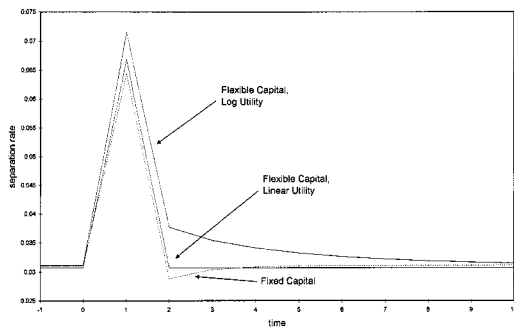


FIGURE 2B. EFFECT OF ONE-TIME NEGATIVE PRODUCTIVITY SHOCK ON ENDOGENOUS SEPARATION RATE

struction as a propagation mechanism is influenced by capital adjustment. With linear utility and flexible capital, reductions in the capital stock following a negative shock are induced by reductions in employment, leading to greater output effects. In addition, fixing the capital stock serves to drive down the rental rate and dampen the employment effects. It is worth noting that there would be no capital adjustment whatsoever in the RBC model given linear utility and a one-time productivity shock, and thus the shock would not be propagated at all. Moreover, there is no propagation in our model when all separations are exogenous; this occurs because vacancies do not fluctuate when the productivity shock is not itself persistent.

### C. Consumption Smoothing

Introducing a consumption-smoothing motive increases the power of this propagation mechanism. In the face of the negative shock, the representative household will support con-

sumption by making further reductions in investment, driving up both the rental rate and the endogenous separation rate. This may be seen in Figure 2, which shows equilibrium paths for the case in which capital is flexible, but the utility of consumption is given by  $\log C_t$  (i.e., we set  $\gamma = 1$ ). The rental rate in Figure 2A now lies above the steady-state level in period 2, and returns to the steady state only gradually. This reflects reductions in household investment that serve to lower capital supply and drive up the equilibrium rental rate. Correspondingly, the endogenous separation rate in Figure 2B is increased relative to the linear-utility case, both in the period of impact and in succeeding periods. Figure 2C verifies that consumption smoothing leads to much larger negative output effects in periods following the shock.

## III. Quantitative Assessment

### A. Separation and Matching Probabilities

To assess the quantitative importance of the propagation mechanism implied by our model, we must obtain measurements of separation and matching probabilities for use in calibration. These are derived from relationships between stocks and flows arising in a deterministic steady state of the model. Let  $N^s$  denote the steady-state stock of employment relationships, and let  $U^s$  and  $V^s$  represent the per-period flows of workers and firms, respectively, through the matching pools in the steady state. The probability of separation, for either exogenous or endogenous reasons, is indicated by  $\rho$ , so that  $\rho N^s$  gives the total flow of workers and firms



out of employment relationships within a given period. Note that  $\rho = \rho^x + (1 - \rho^x)\rho^n$ , where  $\rho^n$  gives the endogenous separation rate in the steady state.

Several direct measures of  $\rho$  are available. In surveying the empirical evidence, Hall (1995 p. 235) concludes that, for long-term employment relationships of the sort we consider, quarterly U.S. worker separation rates lie in the range of 8 to 10 percent. Using Current Population Survey (CPS) data, Davis et al. (1996 p. 35) compute an annual separation rate of 36.8 percent, which works out to roughly 11 percent per quarter. From these estimates, we take  $\rho = 0.10$  as our estimate of the quarterly steady-state rate of exogenous and endogenous separation.

To interpret exogenous and endogenous components of the separation rate, we make the assumption that firms experiencing exogenous separations attempt to refill the positions by posting vacancies in the ensuing matching phase, while firms having endogenous separations do not post vacancies. This assumption makes sense if exogenous separations are regarded as being worker-initiated, reflecting changes in the workers' personal circumstances. Such separations give rise to job vacancies that are reposted by the firm in the current period.<sup>12</sup> Endogenous separations, in contrast, may reasonably be viewed as reflecting on the firms' circumstances, where firms would not attempt to rehire following such separations. It follows that the rate at which separations are reposted by firms, denoted by  $\omega^f$ , will be equal to the proportion of all separations that are exogenous, or  $\omega^f = \rho^x/0.10$ .

Period-to-period job destruction is recorded as total separations  $\rho N^s$  less those job openings that are reposted and successfully refilled by firms within the period. The steady-state mass of jobs destroyed per period is thus given by  $\rho(1 - \omega^f\lambda^f)N^s$ , where  $\lambda^f$  indicates the steady-state matching probability for a firm. Job creation is recorded as the mass of firms that have no employees at the beginning of the period but

that find workers in the matching phase of the period. Therefore,  $\lambda^f(V^s - \rho\omega^fN^s)$  is the mass of jobs created each period in the steady state. Job destruction must equal job creation in the steady state:

$$(15) \quad \rho(1 - \omega^f\lambda^f)N^s = \lambda^f(V^s - \rho\omega^fN^s).$$

Although the data is restricted to the manufacturing sector, the LRD evidence reported in Davis et al. (1996 p. 19) allows us to pin down directly the job-creation rate. From quarterly plant-level data from U.S. manufacturing, 1972:2–1988:4, we find the ratio of creation to employment to be:

$$(16) \quad \frac{\lambda^f(V^s - \rho\omega^fN^s)}{N^s} = 0.052.$$

Further, Davis et al. (1996 p. 23) indicate that 72.3 percent of jobs counted as destroyed in a quarter fail to reappear in the following quarter (i.e., for plants experiencing employment reductions in a quarter, roughly three-quarters of the reduction persists into the following quarter). This implies:

$$(17) \quad \rho(1 - \omega^f(\lambda^f + (1 - \lambda^f)\lambda^f))N^s = 0.723\rho(1 - \omega^f\lambda^f)N^s.$$

Combining (15), (16), and (17) yields  $\lambda^f = 0.71$  and  $\omega^f = 0.68$ . Using our assumption that only exogenous separations are reposted, we then calculate  $\rho^x = 0.068$ . Correspondingly, the steady-state endogenous separation rate is computed to be  $\rho^n = 0.032$ .<sup>13</sup>

It remains to estimate the steady-state matching probability for workers. Blanchard and Diamond (1990) use CPS data for 1968–1986

<sup>12</sup> This approach reflects the observation that flows of workers out of employment relationships exceed flows of jobs out of firms; in other words, worker flows exceed job flows (see Davis et al., 1996 pp. 34–36). As a consequence, a substantial proportion of the firms that experience separations will desire to replace the lost workers, and will be successful at doing so, within the current period.

<sup>13</sup> It is worth noting that our finding of  $\lambda^f = 0.71$  agrees with Jan van Ours and Geert Ridder's (1992) result from Dutch survey data that 71 percent of vacancies reported in an initial survey were found to be filled in a follow-up survey roughly one quarter later. As a further check on our estimates, we calculated that in the steady state, the estimates of  $\rho$ ,  $\lambda^f$ , and  $\omega^f$  imply that 65 percent of the jobs destroyed in a quarter do not reappear in the second quarter following. This number is reasonably close to Davis et al.'s (1996 p. 23) corresponding figure of 59 percent.

to calculate an average stock of employed workers of 93.2 million. In abstracting from labor-force participation decisions, we interpret unmatched workers in our model as including both workers classified as unemployed and those not in the labor force but stating that they “want a job,” giving an average stock of unmatched workers of 11.2 million. Thus, the steady-state ratio of unmatched to matched worker stocks is estimated to be 12 percent. In our model, we identify the mass of workers observed to be unemployed as  $1 - N^s$ , which equals  $U^s - \rho N^s$  in the steady state. Note that this excludes workers with very short transitional terms of unemployment due to leaving one job and initiating another within the same period. The steady-state condition for worker flows, corresponding to the job-flow condition (15), may be written:

$$(18) \quad \rho(1 - \lambda^w)N^s = \lambda^w(U^s - \rho N^s).$$

Combining (18) with our earlier findings  $\rho = 0.10$  and  $(U^s - \rho N^s)/N^s = 0.12$ , we conclude that  $\lambda^w = 0.45$  gives an appropriate estimate.

### B. Calibration and Empirical Evaluation

We solve the model under the aggregate productivity process  $\ln z_t = \xi \ln z_{t-1} + \varepsilon_t$ , where  $\varepsilon_t$  is taken to be independently and identically distributed (i.i.d.) normal with unit mean and standard deviation  $\sigma_\varepsilon$ . Further,  $a_t$  is assumed to be i.i.d. lognormal with zero mean and standard deviation  $\sigma_a$ .<sup>14</sup> In selecting parameter values, we make standard choices for the parameters  $\alpha$ ,  $\delta$ ,  $\gamma$ ,  $\beta$ ,  $\xi$ , and  $\sigma_\varepsilon$ , as summarized in the first column of Table 1.<sup>15</sup> We give the worker and

<sup>14</sup> Solutions to the model are computed by expressing the equilibrium conditions in recursive form and calculating equilibria using the parameterized-expectations algorithm, as discussed by Lawrence J. Christiano and Jonas D. M. Fisher (1994); see our working paper for details. The working paper also reports accuracy tests of the solution, which document that the solution is very accurate.

<sup>15</sup> Hansen and Randall Wright (1992), for example, make these selections in their analysis of labor-market implications of RBC models. Although we cannot directly invoke factor share comparisons in our setting, the choice of  $\alpha = 0.36$  does yield a quarterly output/capital ratio of roughly 10 percent in our simulated data, in line with U.S. evidence.

TABLE 1—PARAMETER VALUES

$\alpha$	0.36	$\pi$	0.50
$\delta$	0.025	$\rho^x$	0.068
$\gamma$	-1.00	$l$	1.27
$\beta$	0.99	$b$	2.220
$\xi$	0.95	$c$	0.203
$\sigma_\varepsilon$	0.007	$\sigma_a$	0.101

TABLE 2—DATA MATCH FOR PARAMETER SELECTION

	U.S. data	Model
$\rho^n$	0.032	0.034
$\lambda^f$	0.71	0.70
$\lambda^w$	0.45	0.45
$\sigma_N/\sigma_Q$	0.63	0.63

firm equal bargaining power by setting  $\pi = 0.5$ , and the choice of  $\rho^x$  is discussed in Section III, subsection A.<sup>16</sup> The remaining four parameters,  $l$ ,  $b$ ,  $c$ , and  $\sigma_a$ , are selected to match statistics from simulated data to empirical measures of the endogenous separation rate and the worker and firm matching probabilities, derived in Section III, subsection A, along with a measure of the variability of employment relative to output, which in the simulated data is sensitive to the level of  $\sigma_a$ .

The first three rows of Table 2 report separation and matching probabilities derived in Section III, subsection A, along with values computed from steady states of the model having deterministic aggregate productivity. The fourth row considers the ratio of the standard deviation of employment to the standard deviation of output.<sup>17</sup> Actual and simulated data for the latter case are logged and Hodrick-Prescott (H-P) filtered. As seen in Table 2, the simulated data produce good matches along the four dimensions considered.

<sup>16</sup> Robustness of our propagation results to the choice of  $\pi$  is demonstrated in our working paper.

<sup>17</sup> Data series for Table 2, row four, measure employment and output by converting monthly nonagricultural employment and industrial production for U.S. manufacturing, expressed on a per capita basis, into quarterly series starting at the middle month of each quarter for 1972:2–1988:4, in line with the LRD employment measures. For the model, this ratio is estimated by generating 100 simulated samples of 267 observations each, where initial conditions are randomized by ignoring the first 200 observations. This procedure is also used to generate model statistics in the tables below.

TABLE 3—COMPARISON OF U.S. AND MODEL DATA

	U.S. data	Model
A		
$\sigma_Q$	1.93 (0.0024)	1.45
$\sigma_C/\sigma_Q$	0.44 (0.16)	0.55
$\sigma_I/\sigma_Q$	3.06 (0.057)	2.71
$\sigma_{Q/N}/\sigma_Q$	0.42 (0.30)	0.40
B		
$\sigma_{cre}/\sigma_N$	4.71 (0.025)	7.48
$\sigma_{des}/\sigma_N$	6.86 (0.012)	6.17

Notes: U.S. data are 1972:2–1988:4. All series are logged and H-P filtered. Standard errors are in parentheses.

Evaluation of the model's performance relative to U.S. aggregate data is given in Panel A of Table 3.<sup>18</sup> We also consider the ability of the model to account for characteristics of the LRD data. Consistent with our measurement procedure, as expressed in equation (15), we define rates of job creation and destruction in the simulated data as follows:

$$(19) \quad cre_t = \lambda_t^f (V_t - \rho^x N_t) / N_t,$$

$$des_t = \rho_t - \rho^x \lambda_t^f,$$

where  $\rho_t$  denotes the realized separation rate in period  $t$ . Thus, job creation is comprised of total matches in period  $t$  net of those matches serving to fill separations that are reposted within the period, while job destruction is given by total separations net of those that are refilled within the period. Panel B of Table 3 compares volatilities of job creation and destruction relative to manufacturing employment in the LRD and

<sup>18</sup> Data series for Table 3, Panel A and Figure 5 are seasonally adjusted, quarterly, taken from CITIBASE. The variable  $Q$  denotes real gross domestic product (GDPQ), divided by over-age-16 population, including resident armed forces, middle month (PO16). The variable  $C$  denotes real consumption of nondurables (GCNQ) plus real consumption of services (GCSQ) plus real government consumption expenditures and gross investment (GGEQ), all divided by PO16. The variable  $I$  denotes real expenditures on durable consumption (GCDQ) plus real investment (GIFQ), all divided by PO16. The variable  $N$  denotes civilian labor force, total employment, monthly (LHEM), converted to quarterly by simple averaging, divided by PO16. It should be noted that measured consumption in the simulated data includes only consumption of market-produced output, in line with the empirical consumption data.

simulated data.<sup>19</sup> The chief discrepancy between model and observation is that job creation is too volatile in the simulated data.

Dynamic correlations between creation, destruction, and manufacturing employment are presented in Table 4. In the LRD data, destruction tends to lead employment, in the sense that employment exhibits a large negative correlation with destruction lagged two quarters. Further, creation tends to lag employment. As may be observed in the table, the model displays remarkable agreement with the data, with signs and magnitudes of covariances being quite close. In particular, employment has a large negative correlation with past destruction and future creation, and there is a large, negative contemporaneous correlation between creation and destruction.

The cyclical variation in job creation and destruction implied by the model is illustrated in Figure 3, which shows impulse responses for a one-standard-deviation negative aggregate productivity shock. On impact, a large destruction spike is induced by an increase in the job-destruction margin, accompanied by a smaller dip in creation, as firms post fewer vacancies in anticipation of lower future aggregate productivity. The induced increase in unemployment following the shock drives creation above its preshock levels. This "echo effect" operates with a one-period lag in the model, as opposed to a two-period lag in the data, as the creation/destruction correlations indicate.

### C. Quantitative Significance of Propagation

We now assess the degree to which productivity shocks in our model are amplified and made more persistent. To clarify the discussion, we break down our measurement of propagation effects into two categories. First, a produc-

<sup>19</sup> Data series for Tables 3 (Panel B) and 4 are quarterly, seasonally adjusted by regressing the log of each series on seasonal dummies. The variable  $cre$  denotes job-creation rate for both startups and new establishments (POS), from Davis et al.'s "Job Creation and Destruction" database. The variable  $des$  denotes job-destruction rate for both shut-downs and new establishments (NEG), from "Job Creation and Destruction" database. The variable  $N$  denotes employees on nonagricultural payroll, manufacturing, monthly (LPM6), from CITIBASE, transformed into quarterly series starting at the middle month of each quarter, divided by PO16.

TABLE 4—DYNAMIC CORRELATIONS OF JOB FLOWS

		-3	-2	-1	0	1	2	3
Cov[cre <sub>t+k</sub> , N <sub>t</sub> ]	U.S. data	0.27	0.15	0.04	-0.19	-0.58	-0.68	-0.60
	Model	0.17	0.13	0.06	-0.14	-0.70	-0.68	-0.52
Cov[des <sub>t+k</sub> , N <sub>t</sub> ]	U.S. data	-0.63	-0.65	-0.59	-0.35	-0.01	0.29	0.45
	Model	-0.35	-0.53	-0.72	-0.78	-0.24	-0.02	0.08
Cov[cre <sub>t+k</sub> , des <sub>t</sub> ]	U.S. data	-0.39	-0.44	-0.47	-0.43	-0.14	0.18	0.34
	Model	-0.13	-0.14	-0.22	-0.47	0.43	0.57	0.48

Notes: U.S. data are 1972:2–1988:4. All series are logged and H-P filtered.

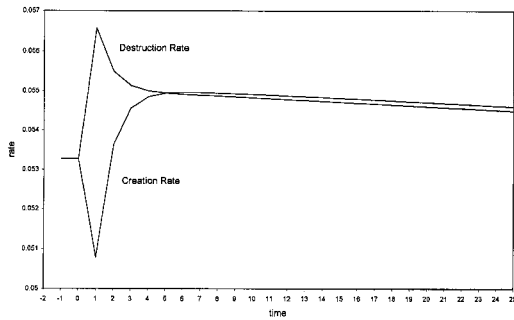


FIGURE 3. IMPULSE RESPONSES OF JOB CREATION AND DESTRUCTION TO A NEGATIVE PRODUCTIVITY SHOCK

tivity shock may be magnified in its effect on output within the period that the shock occurs, which we refer to as *impact magnification*. Second, following the initial period, the output effect of the shock may die away more slowly than the effect on productivity, so that the shock has a more persistent effect on output. The combined effects of impact magnification and persistence give rise to *total magnification* of the shock, reflecting the greater effect on output in all periods. Impact magnification is obtained by comparing the output reduction associated with a one-standard-deviation negative productivity shock with the corresponding productivity reduction. We measure total magnification by the ratio of the standard deviation of output to the standard deviation of productivity.

Table 5 reports impact and total magnification for our endogenous job destruction (EJD) model, as well as for a standard RBC model with variable hours and Hansen’s (1985) indivisible labor model (other columns are explained below). All three models generate impact magnification, in the sense that the output adjustment exceeds the reduction in productivity. The RBC model generates impact magnification that is somewhat greater

than that generated by the EJD model, while the Hansen model delivers still greater impact magnification. Total magnification in the EJD model, in contrast, is much larger than is impact magnification, indicating that the model generates significant persistence. Total magnification is just under twice as large as impact magnification, with productivity shocks being magnified roughly two and one-half times in their effect on output. In contrast, impact and total magnification are virtually the same in the RBC and Hansen models, indicating that persistence is nil.

These results are expressed graphically in Figure 4, which presents impulse responses for aggregate productivity together with output in the three models. In the RBC and Hansen models, the shock is magnified in the initial period, but thereafter output dynamics track the productivity dynamics very closely. Persistent output effects are vividly apparent for the EJD model, however, as the adjustment of output toward the steady state is much slower than the productivity adjustment.

The added persistence introduced by our model is helpful for explaining the autocorrelation structure observed in U.S. data. Figure 5 depicts the autocorrelations of output growth rates in U.S. GNP over the period 1961:1–1993:4, together with corresponding autocorrelations for output growth in the EJD and RBC models.<sup>20</sup> Autocorrelations for the growth rate of the aggregate productivity shock are roughly equivalent to the horizontal axis and have been omitted from the figure. The EJD model accounts for much of the difference between the GNP data and the productivity shock, especially in the first-order autocorrelations, while the

<sup>20</sup> Autocorrelations in the Hansen model are nearly identical to those in the RBC model.

TABLE 5—IMPACT AND TOTAL MAGNIFICATION

	EJD	RBC	Hansen	Fixed capital	Exogenous separation	CCA
Impact magnification	1.28	1.57	1.86	1.30	1.00	1.52
Total magnification	2.45	1.55	1.86	1.85	1.25	2.85

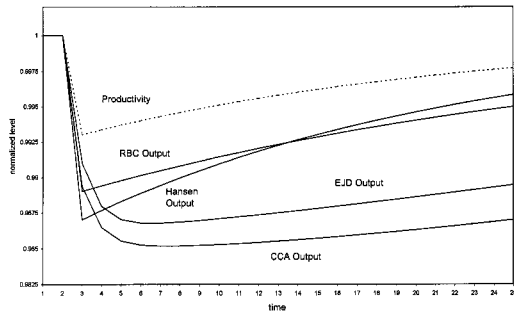


FIGURE 4. IMPULSE RESPONSES OF PRODUCTIVITY AND OUTPUT TO A NEGATIVE PRODUCTIVITY SHOCK

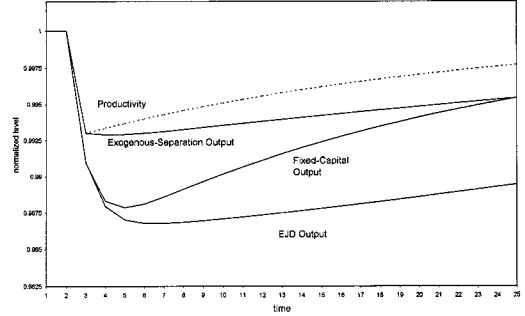


FIGURE 6. IMPULSE RESPONSES OF PRODUCTIVITY AND OUTPUT TO A NEGATIVE PRODUCTIVITY SHOCK

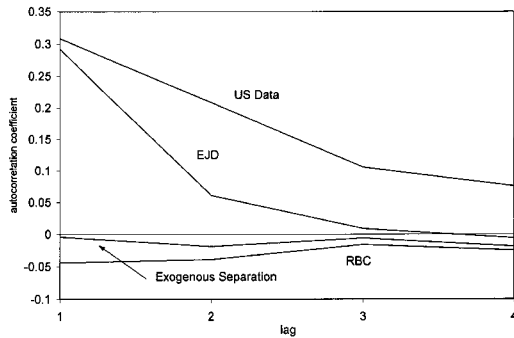


FIGURE 5. AUTOCORRELATIONS OF OUTPUT GROWTH RATES

RBC model generates autocorrelations that are substantially equivalent to those of the shock.

To assess the importance of interactions between capital adjustment and fluctuations in the job-destruction rate, we recompute equilibria of the model under two alternative scenarios: first, the capital stock is fixed at its steady-state level (“Fixed Capital”); and second, all separations are exogenous, with the exogenous separation rate set at 10 percent (“Exogenous Separation”).<sup>21</sup> As seen in Table 5, impact magnifica-

tion in the case of a fixed capital stock is equal to that of the EJD model, but total magnification is substantially lower in the former case, reflecting lower persistence of output effects in the absence of capital adjustment. Impulse responses for output are given in Figure 6, where the added persistence contributed by capital adjustment shows up clearly.

Impact magnification in the exogenous separation case is virtually nonexistent, as seen in Table 5. Thus, output reductions remain small relative to the EJD model, and total magnification is only 1.25. Figure 6 illustrates this comparison graphically. Autocorrelations for the exogenous separation case, shown in Figure 5, represent a slight improvement over the RBC model but are still far from those observed in the data. From this we conclude that fluctuations in the job-destruction rate are central to producing the impulse magnification and persistence underlying our total magnification results.<sup>22</sup>

*b* = 0 and  $\rho^x = 0.10$ ; since home production is zero, workers and firms will never voluntarily sever their relationships, and all separations are exogenous. The Table 1 parameters are used for this case also, except that *c* = 2.35 is specified to better match the U.S. data.

<sup>22</sup> Our finding of little persistence in the exogenous separation case may appear to conflict with results of Andolfatto (1996), who considers a dynamic general-equilibrium

<sup>21</sup> In the fixed-capital scenario, equilibria are recomputed using the parameters of Table 1, with the capital stock fixed at its steady-state value, so that (12) does not apply. The exogenous separation scenario is implemented by setting



### D. Persistent Idiosyncratic Productivity

Thus far we have restricted attention to the case of i.i.d. idiosyncratic productivity shocks. It is more realistic, however, to allow for persistent productivity differences across firms. Further, Hall (1999) has linked persistent productivity differences to concentration of job-destruction spikes in the U.S. data.<sup>23</sup> Thus, it is important to ask whether our propagation results are consistent with the presence of idiosyncratic persistence.

To assess this issue, let the production function now be given by  $z_t a_{it} d_{it} f(k_{it})$ , where  $d_{it}$  indicates a persistent component of idiosyncratic productivity, and the other variables are defined as before. Assume that  $d_{it}$  may assume two possible values and that the realization of  $d_{it}$  for a particular employment relationship is determined once and for all when the match is first formed. The processes for  $z_t$  and  $a_{it}$  are specified as before. The parameters for the modified model are the same as in Table 1, except that  $\sigma_a$  is lowered to 0.055 in order to generate the same volatility of H-P-filtered aggregate output as under the original parameterization. The possible values of  $d_{it}$  are 0.99 and 1.01, each realized with probability 0.5.<sup>24</sup> For this version of the model, total magnification becomes 2.43, which is essentially unchanged from the earlier results. We conclude that our propagation results can be extended to a setting

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model with labor-market matching and an exogenous separation rate. Part of the difference is explained by the fact that, in calibrating his model, Andolfatto utilizes a quarterly worker matching probability of roughly 20 percent, which implies an unemployment duration of five quarters. Andolfatto obtains this measurement by including in the worker matching pool *all* adults who are out of the labor force, together with the unemployed. Recomputing the equilibrium of the exogenous separation case of our model using Andolfatto's worker matching probability yields a significant increase in persistence.

<sup>23</sup> Hall argues that destruction spikes involve substantial numbers of "vulnerable" employment relationships, having persistently low idiosyncratic productivity. Subsequent spikes cannot occur until the stock of vulnerable relationships has been rebuilt. The modified model discussed below does exhibit this concentration effect.

<sup>24</sup> This represents a very large persistent effect: the increase in the equilibrium value of a match drawing  $d_{it} = 1.01$  versus  $d_{it} = 0.99$  amounts to 28 percent of per capita output.

that incorporates persistent idiosyncratic productivity shocks.<sup>25</sup>

### IV. Costly Capital Adjustment

Thus far we have explored how interactions between capital adjustment and job destruction serve to propagate shocks when capital is costless to adjust. The propagation mechanism becomes considerably stronger, however, when capital adjustment is costly. Further, the assumption of significant capital-adjustment costs seems plausible empirically.<sup>26</sup> In this section we modify our model to assess the importance of this effect. To avoid complications, the modified model ties capital-adjustment costs to imperfections in negotiating rental contracts.

In contrast to the setup in Section I, subsection A, we now assume that the firm selects capital  $k_{it}$  before observing the idiosyncratic productivity shock  $a_{it}$  and the exogenous separation shock. The aggregate shock  $z_t$  is still observed before  $k_{it}$  is chosen. When capital is selected, the firm obtains an option to use  $k_{it}$  units of capital at a cost of  $r_t$  per unit. We assume that the firm can avoid making payments for capital if the relationship is severed, i.e., the firm may declare bankruptcy in lieu of making payments. Thus, the firm's optimal choice of capital now solves the following problem:

$$\max_{k_{it}} \int_{a_{it}}^{\infty} [z_t a_{it} k_{it}^{\alpha} - r_t k_{it}] d\mu(a_{it}),$$

where the value of  $a_{it}$  is determined by:

$$z_t a_{it} (k_{it}^*)^{\alpha} - r_t k_{it}^* + g_{it} = b + w_{it}^w.$$

These conditions replace the earlier equations

<sup>25</sup> In this modification of the model, a negative productivity shock will destroy a larger percentage of relationships having the lower value of  $d_{it}$ , and following the shock there will be fewer of these low-productivity relationships; this is a version of Hall's (1999) concentration effect. Total magnification remains high despite the concentration effect, however, since the lower value of the standard deviation of  $a_{it}$  operates to increase the average output loss associated with breakups.

<sup>26</sup> Valerie A. Ramey and Matthew D. Shapiro (1998b), for example, study cases in which equipment is resold at a significant discount following factory liquidations.

(1) and (2). Note that  $k_{it}^*$  no longer depends on  $a_{it}$  in this case.

Since rental payments are not obtained from firms whose employment relationships are severed, the household wealth constraint (6) is replaced by:

$$C_t + K_{t+1} = I_t + B_t + ((1 - \rho^x)(1 - \rho_t^n)r_t + 1 - \delta)K_t.$$

Finally, the capital-market equilibrium conditions (11) and (12) are replaced by:

$$N_t k_t^* = K_t,$$

$$C_t^{-\gamma} = \beta E_t [C_{t+1}^{-\gamma} ((1 - \rho^x) \times (1 - \rho_{t+1}^n)r_{t+1} + 1 - \delta)].$$

Our notion of capital-adjustment costs is motivated by the idea that renting capital to a firm involves a certain amount of commitment by the capital supplier (e.g., firms differ in their locations or engineering specifications, so that capital is not immediately transferable across firms). Further, firms are unable to commit contractually to making rental payments under future contingencies. When productivity turns out to be low *ex post*, the firm can walk away from the rental contract, and the supplier is left to bear the cost of idle capital for one period.<sup>27</sup>

We recalibrate the model under the assumption of costly capital adjustment, obtaining results closely comparable to those reported in Tables 3 and 4 for the costless adjustment case.<sup>28</sup> In Table 5 it may be observed that the costly capital-adjustment (CCA) model leads to

significant increases in impact and total magnification, relative to the benchmark EJD model without capital-adjustment costs. Productivity shocks in the CCA case are magnified nearly three times in their effect on productivity. The impulse response of output in the CCA case is shown in Figure 4, where the greater amount of total magnification shows up clearly. Further, autocorrelations of output growth rates are very similar to those shown in Figure 5 for the EJD model.<sup>29</sup>

## V. Conclusion

In this paper we have analyzed a macroeconomic propagation mechanism associated with cyclical fluctuations in the job-destruction rate. The model endogenizes the determination of the job-destruction rate as part of a dynamic general equilibrium with labor-market matching. Quantitatively significant propagation effects are demonstrated, both with respect to magnification of shocks on impact and persistence of output effects. Interactions between capital adjustment and the job-destruction rate, linked to reductions in capital demand and household investment, play an important role in propagating shocks. Our results suggest that interdependencies between capital and labor markets may be of central importance in propagating shocks. Further, policies that counteract the negative effects of recessionary investment reductions, by boosting investment or strengthening employment relationships during recessionary episodes, have the potential to provide significant benefits.

A useful extension of the current model would involve closer examination of the nature of capital and labor adjustment and the sources of aggregate shocks. Recent work by Ramey and Shapiro (1998a) has focused on costs of reallocating capital across sectors in the face of shocks to government spending. Incorporating these ideas into the current framework would make possible a rich synthetic analysis of factor adjustment. A further useful extension would

<sup>27</sup> This specification of rental contracting rules out the possibility of renegotiating a lower rental payment to the capital supplier when this is mutually beneficial. We adopt this specification in order to avoid substantial complications arising from three-way renegotiation between firms, workers, and capital suppliers. Such renegotiation would serve to lower the job-destruction margin relative to the simpler version without renegotiation. We believe this should not significantly affect the propagation results, however, once the model is recalibrated to account for the lower job-destruction margin.

<sup>28</sup> Parameters are the same as in Table 1, except that  $b = 2.077$ ,  $c = 0.196$ , and  $\sigma_a = 0.098$ . See our working

paper for empirical evaluation of the model with costly capital adjustment.

<sup>29</sup> It should be noted that idle capital imposes a high social cost in the CCA model. Moving from the CCA to the EJD model under the CCA parameters raises output and consumption by 21 percent each in the steady state.

incorporate imperfectly contractible choices by the worker and firm, as considered by Ramey and Watson (1997) and den Haan et al. (2000), into the production process. Social costs of job loss would depend on the extent to which separation is driven by the attendant fragility of employment contracts, as opposed to outside worker benefits of the form analyzed in the present paper.

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