NBER WORKING PAPERS SERIES

THE CLEANSING EFFECT OF RECESSIONS

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Working Paper No. 3922

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
December 1991

Respectively: Columbia University and NBER, Columbia University.
We thank John Haltiwanger for helpful comments and providing us with job flow data, Olivier Blanchard, Peter Diamond, Julio Rotemberg and participants at Chicago, Maryland, Boston College and the NBER Summer Institute 1991 for useful comments. Ricardo Caballero thanks the National Science Foundation, the Alfred P. Sloan Foundation and the NBER (John Olin Fellowship) for financial support. This paper is part of NBER's research program in Economic Fluctuations. Any opinions expressed are those of the authors and not those of the National Bureau of Economic Research.

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ABSTRACT

This paper investigates the response of industries to cyclical variations in demand in the context of a vintage model of "creative destruction." Due to process and product innovation, production units that embody the newest techniques are continuously being created, and outdated units are being destroyed. We investigate the extent to which changes in demand are accommodated on the creation or destruction margins. Although outdated production units are the most likely to turn unprofitable and be scrapped in a recession, they can be "insulated" from the fall in demand if it is accompanied by a reduction in the creation rate. The model's implications are broadly consistent with observed variations in manufacturing gross job flows. The calibrated model matches the relative volatilities of job creation and destruction, and their asymmetries over the cycle.

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1 Introduction

This paper investigates the response of industries to cyclical variations in demand in the framework of a vintage model of "creative destruction." Our premise is that the continuous process of creation and destruction of production units that results from product and process innovation is essential in understanding not only growth, but also business cycles.[2] This idea goes back at least to Schumpeter (1939, 1942), although we do not go so far as to adopt his view that the process of creative destruction is itself a major *source* of economic fluctuations (as in Shleifer 1986), but only that it plays an important role in their transmission.

Most recently, looking at gross job flow data, Blanchard and Diamond (1990) have emphasized the plausibility of creative destruction in accounting for the simultaneous high observed rates of job creation and destruction in narrowly defined sectors, and have argued for its potential importance in explaining the cyclicality of job flows (see also Davis and Haltiwanger 1991). In this context, there are two margins along which industries can accommodate variations in demand: they can either vary the rate at which production units that embody new techniques are created, or the rate at which outdated units are destroyed. The central question becomes, along which of these two margins will business cycles be accommodated?

The evidence from job flows was documented by Davis-Haltiwanger (1990, 1991) and Blanchard-Diamond (1990), who find that cyclical variations are significantly more pronounced in job destruction than they are in job creation. Blanchard and Diamond point out that an explanation along creative destruction lines of the greater cyclicality of job destruction implies that recessions are times of "cleaning up," when outdated or relatively unprofitable techniques and products are pruned out of the productive system—an idea that was popular among pre-Keynesian "liquidationist" theorists like Hayek or Schumpeter (see De Long 1990), but need not be taken to imply, as those authors did, that recessions are "desirable" events.

What determines theoretically which margin is more responsive? We answer this question in the context of a simple model of creative destruction.[3] Production units embody

[2]For an analysis of creative destruction in a vintage model of embodied technical progress, see Sheshinski (1967) and references therein. For a recent model of growth through creative destruction, see Aghion and Howitt (1991).

[3]A steady-state variant of our model has been used by Jovanovic and Lach (1989) to study technology diffusion.

the most advanced techniques available at the time of their creation. Creation costs slow down the process of technology adoption and lead to the coexistence of production units of different vintages. This decouples the two margins and permits a meaningful analysis of the issue at hand.

The interaction of two margins can challenge one's intuition. We isolate two effects. Old production units, having an inferior technology, can more easily turn unprofitable and be scrapped in a recession than new ones. However, units in place may not experience the full fall in demand if it is accommodated by a reduction in the creation rate. We investigate the extent to which this "insulating" effect of creation will operate and reduce the responsiveness of destruction to demand.

Davis and Haltiwanger's (1990, 1991) data on manufacturing job flows are then analyzed in light of our model. Despite its simplicity, the model matches well such broad features of the data as the relative volatility of job creation and destruction and the nonlinear conditional response of job flows to positive and negative changes in demand.

In section 2 below, we lay out our basic vintage model of creative destruction and characterize its steady state. Section 3 introduces demand fluctuations into the model, and asks which of the creation or destruction margins will respond to them. Section 4 interprets the data on manufacturing job flows in terms of our model, and ends with a calibration exercise in which the model's theoretical response to the observed path of manufacturing activity is calculated and compared to the actual response.

2 A Vintage Model of Creative Destruction

In this section, we present the basic features of the model of creative destruction that is used throughout the paper. The first subsection describes the basic statistics of the model; section 2.2 turns to market equilibrium conditions; and section 2.3 characterizes the model's steady state.

2.1 Production Units: Distribution and Flows

We model an industry experiencing exogenous technical progress. New production units that capture the most advanced techniques are continuously being created, and outdated ones are being destroyed. Because the creation process is costly, production units with different productivities coexist.[4]

More specifically, labor and capital combine in fixed proportions to form *production units.* A production unit created at time t_0 embodies the leading technology at t_0, and produces the same constant flow $A(t_0)$ of output throughout its lifetime. Technical progress makes the productivity $A(t)$ of the leading technology at time t grow at an exogenous rate $\gamma > 0$.

Although we interpret the creation process as one of technology adoption, it could also be interpreted as one of product innovation. In this case, there is a continuum of perfectly substitutable products that yield different utilities. A production unit created at t_0 will be producing a unit flow of the most advanced product in existence at t_0, which yields utility $A(t_0)$.

Since production units that were created at different times (and thus have different productivities) may coexist, we must keep track of their age distribution. Let

$$f(a,t), \qquad 0 \leq a \leq \bar{a}(t),$$

denote the cross-section density of production units aged a at time t, where $\bar{a}(t)$ is the age of the oldest unit *in operation* at time t. The boundary $f(0,t)$ is given by the rate at which new units are created, and the age $\bar{a}(t)$ at which units become obsolete is determined by the destruction process. Our assumptions will be such that $f(a,t)$ and $\bar{a}(t)$ are continuous functions.

The distribution $f(a,t)$ can be aggregated to obtain the total number (or "mass") of production units at any time t:

$$N(t) = \int_0^{\bar{a}(t)} f(a,t)\,da.$$

Because of fixed proportions, $N(t)$ is a measure of both the industry's employment and its capital stock in operation. Industry output is given by

$$Q(t) = \int_0^{\bar{a}(t)} A(t-a)f(a,t)\,da. \tag{1}$$

We now turn to the flows that determine the evolution of the distribution $f(a,t)$. Production units are subject to an exogenous depreciation (or failure) rate $\delta > 0$ and to the

[4] Bresnahan and Raff (1989) give an interesting description of such heterogeneity in the American Auto Industry during the 1929–35 period.

endogenous process of creative destruction. Since the latter turns out to affect $f(a,t)$ only at its boundaries, we know that at any time t the number of units that have survived for a years is given by

$$f(a,t) = f(0,t-a)e^{-\delta a}, \qquad 0 < a \leq \bar{a}(t). \tag{2}$$

Measures of production unit flows can be obtained by differentiating $N(t)$ over time, taking (2) into account:[5]

$$\dot{N}(t) = f(0,t) - [f(\bar{a}(t),t)(1-\dot{\bar{a}}(t)) + \delta N(t)].$$

The first term $f(0,t)$ measures the rate of creation of production units, and the second measures the rate of destruction. When normalized by $N(t)$, they are denoted by $CC(t)$ and $DD(t)$, respectively. The rate of destruction has three components: $f(\bar{a}(t),t)$ units are destroyed because they have reached the obsolescence age $\bar{a}$; $-f(\bar{a}(t),t)\dot{\bar{a}}(t)$ are destroyed because $\bar{a}$ changes over time; and $\delta N(t)$ units depreciate. With some abuse of terminology, we call the sum of the first two components "endogenous destruction." Our assumptions are such that endogenous creation and destruction are always positive, i.e. $f(0,t) > 0$ and $\dot{\bar{a}}(t) < 1$, for all t.

Finally, it will be useful to have an expression for the change in output as a function of the above flows:[6]

$$\dot{Q}(t) = A(t)f(0,t) - [A(t-\bar{a}(t))f(\bar{a}(t),t)(1-\dot{\bar{a}}(t)) + \delta Q(t)]. \tag{1'}$$

2.2 Market Equilibrium

We now turn to supply and demand conditions in this model, and to the economics of creative destruction. We model a perfectly competitive industry in partial equilibrium. Because our main argument does not depend on the presence or absence of uncertainty, we assume perfect foresight.

Supply is determined by free entry and perfect competition. There is a cost c of creating

[5] The derivation involves the partial differential equation $f_t + f_a + \delta f = 0$, $0 < a < \bar{a}(t)$, which follows directly from (2) and corresponds to the basic McKendrick–von Foerster equation in population dynamics (see Nisbet and Gurney (1982)).

[6] Differentiate (1) using $\partial A(t-a)/\partial t = -\partial A(t-a)/\partial a$.

a new production unit:[7]

$$c = c(f(0,t)), \qquad c(.) > 0, c'(.) \geq 0.$$

c is allowed to depend on the creation rate $f(0,t)$ to capture the possibility that, for the industry as a whole, fast creation may be costly and adjustment may not take place instantaneously. This can be due to different reasons. It can arise from a concave production function in the sector producing the industry's capital stock, or from a congestion effect in the matching process characterizing the industry's labor market (e.g., Howitt and McAfee 1987). It can also arise from standard convex capital installation and labor training costs.[8]

As long as creation is taking place, free entry equates a unit's creation cost to the present discounted value of profits over its lifetime. More formally, set the operating cost of a production unit—including wages—to one by choosing it as a numeraire, and let $P(t)$ denote the price of a unit of output. The profits generated at time t by a production unit of age a are

$$\pi(a,t) = P(t)A(t-a) - 1.$$

Now let $T(t)$ measure the lifetime of a unit created at t, which by perfect foresight satisfies

$$\bar{a}(t + T(t)) = T(t). \tag{3}$$

At any time t, the free entry condition is

$$c(f(0,t)) = \int_t^{t+T(t)} \pi(s-t,t)\, e^{-(r+\delta)(s-t)}\, ds, \tag{4}$$

where $r > 0$ is the exogenously given instantaneous interest rate.

To see what determines exit note that, assuming $P(t)$ is continuous, whenever a unit is being destroyed it must be the case that the profits it generates have reached zero. Since

[7] An alternative specification is $c = c(f(0,t)/N(t))$. Normalizing the creation rate by $N(t)$ may be more appealing because it makes the model scale-free. But it complicates things by introducing an additional benefit of creating a production unit, equal to the reduction in future creation costs due to the increase in $N(t)$. We choose the simpler specification to avoid this added complexity.

[8] In this case, because we did not choose the scale-free specification mentioned in the previous footnote, we would need to assume a fixed number (normalized to one) of symmetric, perfectly competitive firms to derive a marginal adjustment cost of the form $c = c(f(0,t))$.

such a unit must be the oldest in operation at that time, $\bar{a}(t)$ must satisfy

$$P(t)A(t-\bar{a}(t)) = 1. \tag{5}$$

This condition relates the price $P(t)$ to $\bar{a}(t)$. From this it is simple to see that the continuity of $\bar{a}(t)$ implies the continuity of $P(t)$, and that $P(t)$ must be decreasing if there is endogenous destruction ($\dot{\bar{a}}(t) < 1$).[9] Since we assume the latter is always taking place, it follows that $P(t)$ is always decreasing and that production units will be destroyed the *first* time their profits hit zero.

The demand side of the model is quite simple. We assume a unit-elastic demand function, and take total spending $\bar{D}(t)$ on the industry's output to be an exogenous and continuous function of time:

$$P(t)Q(t) = \bar{D}(t). \tag{6}$$

An equilibrium in this industry is a path $\{f(0,t), \bar{a}(t), T(t), P(t), Q(t)\}_{t\geq 0}$, that satisfies equations (1)-(6) summarized below:

$$Q(t) = \int_0^{\bar{a}(t)} A(t-a)f(a,t)\,da; \tag{1}$$

$$f(a,t) = f(0,t-a)e^{-\delta a}, \qquad 0 < a \leq \bar{a}(t); \tag{2}$$

$$\bar{a}(t+T(t)) = T(t); \tag{3}$$

$$c\left(f(0,t)\right) = \int_t^{t+T(t)} \left(P(s)A(t) - 1\right) e^{-(r+\delta)(s-t)}\,ds; \tag{4}$$

$$P(t)A(t-\bar{a}(t)) = 1; \tag{5}$$

$$P(t)Q(t) = \bar{D}(t), \tag{6}$$

for all $t \geq 0$, given an initial distribution $f(a,0)$, $a > 0$, of production units. Since the paths of $T(t)$, $P(t)$ and $Q(t)$ are immediately determined from the path $\{f(0,t), \bar{a}(t)\}$ by equations (1)-(3) and (5), we will focus on the latter path as a sufficient description of equilibrium.

Note that instead of using the free entry and exit conditions, equations (4) and (5) could alternatively have been derived as the first-order conditions for maximization of a number of perfectly competitive firms that hold the production units in this industry. This

[9] To see this, differentiate (5): $\dot{P}(t) = -\gamma(1-\dot{\bar{a}}(t))P(t)$.

highlights the efficiency of the resulting equilibrium outcome, and its compatibility with different institutional arrangements. It can also be used to establish the existence and uniqueness of equilibrium (see Hopenhayn 1990).

2.3 Steady State

Before we turn to the response of our industry to demand fluctuations, it is instructive to characterize its steady-state (or balanced growth) equilibrium, assuming demand is a constant $\bar{D}^*$ over time.

In steady state the lifetime of production units is constant: $T(t) = \bar{a}(t) = \bar{a}^*$, for all t; their age distribution is invariant: $f(a,t) = f^*(a)$, for all t; and by (5) the price $P(t)$ must be decreasing at constant rate γ. Equation (2) implies that the distribution of production units in steady state is the truncated exponential distribution illustrated in figure 1:

$$f^*(a) = f^*(0)e^{-\delta a}, \qquad 0 < a \leq \bar{a}^*.$$

The creation rate and destruction age $(f^*(0), \bar{a}^*)$ are jointly determined from free entry and market equilibrium conditions (4) and (6) in steady state. Using (1) and (5) we get

$$c(f^*(0)) = \frac{e^{\gamma\bar{a}^*} - e^{-(r+\delta)\bar{a}^*}}{\gamma + r + \delta} - \frac{1 - e^{-(r+\delta)\bar{a}^*}}{r+\delta}. \tag{7}$$

$$f(0) = \frac{(\gamma+\delta)\bar{D}^*}{e^{\gamma\bar{a}^*} - e^{-\delta\bar{a}^*}}. \tag{8}$$

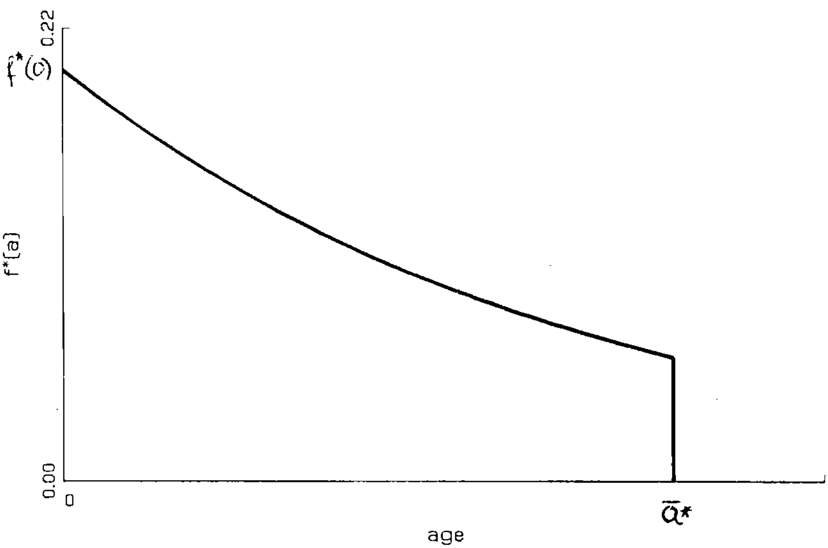
For future use, creation normalized by N is given in steady state by

$$CC^* = \frac{\delta}{1 - e^{-\delta\bar{a}^*}}. \tag{9}$$

The special case when the creation cost is a constant c, independent of the creation rate will be examined closely in what follows. In this case system (7)-(8) is recursive. We can first solve (7) for the steady-state efficient lifetime $\bar{a}^*$ that balances the benefits and costs of updating technology, independently of demand and the rate of creation.[10] Then we can obtain $f^*(0)$ from (8), given $\bar{a}^*$ and the level of demand $\bar{D}^*$.

[10] The effect of different parameters on $\bar{a}^*$ is quite intuitive in this case. $\bar{a}^*$ decreases with γ, since faster technical progress raises the opportunity cost of delaying renovation. It increases with c so as to give more time to recoup higher creation costs. It also increases with r and δ, because they lead to heavier discounting of future profits and make it more difficult to recover creation costs in a short time.

Figure 1
Steady-State Cross Sectional Density
f*(a)



3 Business Cycles

We now turn to the response of the creative destruction process modelled above to cyclical fluctuations in demand. From a pure accounting point of view, our industry has two margins along which it can accommodate, say, a fall in demand $\bar{D}(t)$. As can be seen from (1'), it can either reduce the rate of creation $f(0,t)$ or increase the rate of endogenous destruction $f(\bar{a}(t),t)(1-\dot{\bar{a}}(t))$, which amounts to reducing the age $\bar{a}(t)$ at which units are destroyed (since $f(\bar{a}(t),t)$ is given at t). The issue is, which of these two margins—$f(0,t)$ or $\bar{a}(t)$—will respond to demand fluctuations, and to what extent?

The problem's difficulty comes from the interaction between two margins. For a given creation rate, a fall in demand will cause the most outdated units to turn unprofitable and be scrapped. But if the recession is partly accommodated by a fall in the creation rate, units in place may not suffer its full impact. We argue that the extent to which creation will thus "insulate" existing units from variations in demand depends on the costs of fast creation in the industry, i.e. on $c'(f(0,t))$. The insulating effect of creation will be more complete, the smaller $c'(f(0,t))$ is. In the extreme case where $c'(f(0,t)) = 0$ and adjustment takes place instantaneously, creation will fully accommodate demand fluctuations and destruction will not respond. We start by examining this special case to clarify the insulation mechanism in our model, and then look at what happens more generally when insulation is incomplete.

3.1 The "Insulation" Effect: an Extreme Case

The insulating effect of creation can be best understood in the extreme case where the cost of creation c is a constant, independent of the rate $f(0,t)$ at which it is taking place. In this case adjustment is instantaneous and, as long as the non-negativity constraint on $f(0,t)$ is not binding, the insulation effect is complete. Demand fluctuations are accommodated *exclusively* on the creation margin, and destruction does not respond.

To see why, note that there is a very simple way to solve equilibrium conditions (1)-(6) when $c(f(0,t))$ is constant. As we saw in the analysis of steady state, the system of equations is recursive in this case. We can first solve for $\bar{a}(t)$, using the free entry condition (4) together with (3) and (5). Given that these equations do not depend on the path of $\bar{D}(t)$ and $f(0,t)$, they can be solved independently. But since this is exactly what we did in the analysis of steady state, the solution is the same constant lifetime $\bar{a}^*$ we obtained there, and accordingly a price $P(t)$ falling at constant rate γ.

Given this, we can then solve for the creation rate $f(0,t)$ to satisfy market equilibrium condition (6), using (1) and (2). In other words, the creation rate adjusts continuously to accommodate demand and, from (1'), is given by

$$f(0,t)=\frac{\dot{\bar{D}}(t)+\delta\bar{D}(t)+P(t)A(t-\bar{a}(t))f(\bar{a}(t),t)(1-\dot{\bar{a}}(t))-\dot{P}(t)Q(t)}{P(t)A(t)}, \qquad (10)$$

which we assume yields a non-negative $f(0,t)$.

In the resulting equilibrium, demand fluctuations are fully accommodated by adjustments at the creation margin $f(0,t)$, while $\bar{a}(t)$ remains constant at the destruction margin. The creation process neutralizes the effect of demand fluctuations on the price $P(t)$, thus fully "insulating" existing units from changes in demand. $P(t)$ falls at a constant rate γ that reflects the rate of technical progress, providing the right signal for production units to operate for the constant "efficient" lifetime $\bar{a}^*$.

Note that the above analysis does not imply that the destruction rate will be constant in equilibrium, but only that it does not respond to demand through variations in the age $\bar{a}(t)$ at which units are destroyed. Variations in the destruction rate reflect an "echo" effect of the history of demand on the number $f(\bar{a}^*,t)$ of units that reach the age of obsolescence $\bar{a}^*$.

It is clear from the above proof that, in the constant creation cost case, the full insulation result is robust to any modification of the model that preserves the independence of (3)-(5) from $\{\bar{D}(t)\}$ and $\{f(0,t)\}$. In particular, it does not hinge on the perfect foresight (certainty) assumption, on perfect competition, or on the degree of industry-wide returns to scale. Perfect foresight is not necessary because, as long as it is known that the non-negativity constraint on $f(0,t)$ will never be binding, implementing equilibrium behavior does not require expectations of future demand. Fully accommodating demand on the creation side only requires knowledge of *current* conditions. Perfect competition is not necessary either, since a monopolist's first-order conditions would only add a markup to equations (4) and (5) and preserve the recursive structure of system (1)-(6).[11]

Robustness with respect to industry-wide returns to scale is also straightforward, but will be discussed in some detail for future reference. Assume the simple case where short-run increasing or decreasing returns are due to an industry-wide externality. More specifically, suppose that the output at t of a production unit of age a is $q(t)^{\beta}A(t-a)$, where $q(t)\equiv Q(t)/A(t)$ is aggregate output detrended by the leading technology and is taken as given by firms. In this case, it is simple to see that equilibrium conditions (1)-(6) remain unchanged

[11] In this case the elasticity of demand would have to be greater than one for the monopolist's problem to be well defined.

if we substitute $\tilde{Q}(t) \equiv Q(t)/q(t)^{\beta}$ and $\tilde{P}(t) \equiv P(t)q(t)^{\beta}$ for $Q(t)$ and $P(t)$, respectively. We can then apply the same argument as before on the transformed system to prove that $\bar{a}(t)$ is constant in equilibrium.

3.2 Creation and Destruction over the Cycle

The full insulation effect in the previous section was primarily due the special case of constant creation costs. In reality, the industry may not be able to create all the necessary production units instantaneously in response to a rise in demand. In this section we show that if $c'(f(0,t))$ is positive, insulation will only be partial and destruction will also respond to demand fluctuations.

Once we allow c to depend on $f(0,t)$, system (1)-(6) loses its analytic tractability and must be solved numerically. The solution method we devised is described in the appendix: we turn (1)-(6) into a system of time-varying delay differential equations in $(f(0,t), \bar{a}(t))$ (see Gorecki et al. 1989), develop a "multiple-shooting" method for finding an equilibrium solution for given *arbitrary* values of the path $\{T(t)\}$, and then use an iterative procedure to converge to the right expectations for this path. For all numerical solutions we use the simple linear functional form

$$c(f(0,t)) = c_0 + c_1 f(0,t), \qquad c_0, c_1 > 0. \tag{11}$$

To show the way both creation and destruction respond to demand we generated a sinusoidal demand $\bar{D}(t) = 1 + 0.07\sin(t)$ and solved for the resulting periodic equilibrium.[12] Figure 2 depicts the response of the normalized creation and destruction rates (CC and DD) to the change in demand, $\dot{\bar{D}}(t)$. It is clear that the insulation effect is imperfect and a fall in demand is accommodated partly by a fall in the creation rate, and partly by a rise in the destruction rate.

With increasing creation costs, the industry will want to smooth the creation process and will find it costly to accommodate demand fluctuations fully with variations in $f(0,t)$. Reducing the rate of technology adoption to a near standstill in a recession may require firms to catch up at prohibitively expensive rates in the ensuing expansion. Thus creation will not fully insulate existing units, and part of the contraction will have to take place at the destruction margin. From a purely formal point of view, destruction responds to

[12] We set $r = 0.065$, $\delta = 0.15$ and $\gamma = 0.028$.

Figure 2a: Creation and Destruction
c_0=0.3 c_1=1.0

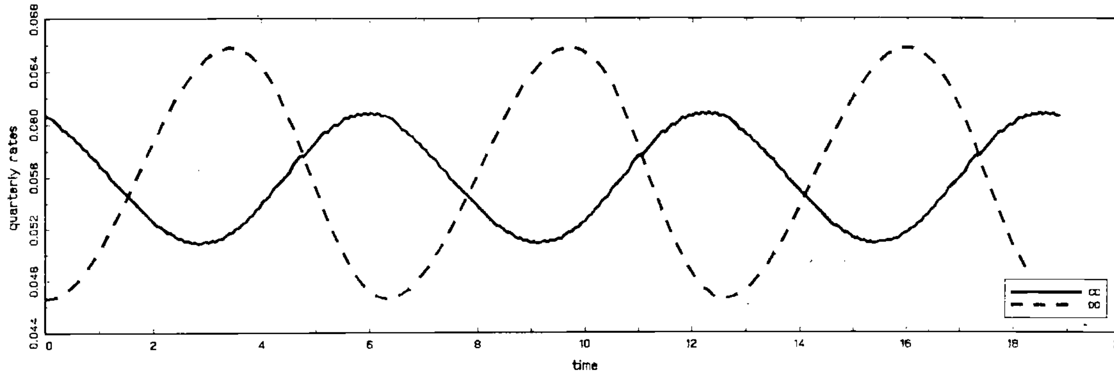
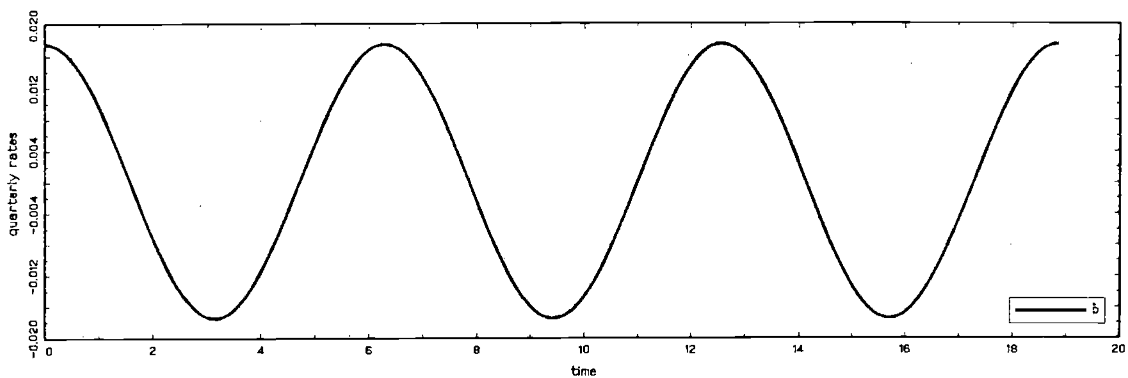


Figure 2b: Change in Demand
(Symmetric)



demand because equations (3)-(5) are no longer independent of the path of $f(0,t)$ and demand.

4 Application to Job Flow Data

In this section we explore the broad consistency of our model with U.S. data on gross job flows. Although this is not meant to be a thorough description of labor markets, we find the match of non-trivial aspects of the job flow data a success for such a stylized model.

4.1 A look at the Data

Production units in our model combine labor and capital in fixed proportions to produce output.[13] One could therefore think of each unit as creating a job in the industry, and use job flow data to measure production unit flows.

Data on job creation and destruction that correspond roughly to our theoretical CC and DD series have been constructed by Davis-Haltiwanger (1990,1991) and Blanchard-Diamond (1990) using different sources. We focus on Davis and Haltiwanger's data, who draw on the Longitudinal Research Database to construct quarterly series for U.S. manufacturing plants for the period 1972:2–1986:4.[14,15]

Since our model analyzes the response of job flows to demand fluctuations, we examine the corresponding relationship in the data. We use output $Q(t)$ to pin down demand empirically, and take the growth rate of the index of industrial production as a measure of output growth.[16] Figure 3 depicts job creation, job destruction and output growth for the manufacturing sector. The relation between these series is analyzed in table 1 using two-digit SIC data. Regressions are run by constraining all coefficients to be equal across sectors, except for a constant.

[13] It is important to notice that our setting does not have specific implications for the allocation of production units across firms and their plants.

[14] Blanchard and Diamond's series are monthly and cover both manufacturing (for the period 1972–81) and the economy as a whole (1968–86). They are based on employment flow data, from the Bureau of Labor Statistics for the manufacturing series and from the Current Population Survey for the economy-wide series.

[15] Because we lack *within* plant measures of gross flows, there is an issue whether the Davis-Haltiwanger series give us a useful measure of total gross job flows. One indication that they do, is that they have major features in common with the Blanchard-Diamond series that are collected from workers rather than plants.

[16] In our basic model $Q(t)$ is a smoothed (by the movements in $P(t)$) version of exogenous demand $\bar{D}(t)$. The degree of smoothing depends on the elasticity of demand, which, for simplicity, we assume to be one in the model. Interestingly, $Q(t)$ can be as volatile as $\bar{D}(t)$ (and $P(t)$ completely rigid) in the external economies version of the model briefly discussed in section 3.1.

Figure 3a. Job Creation and Destruction
U.S. Manufacturing (DH)

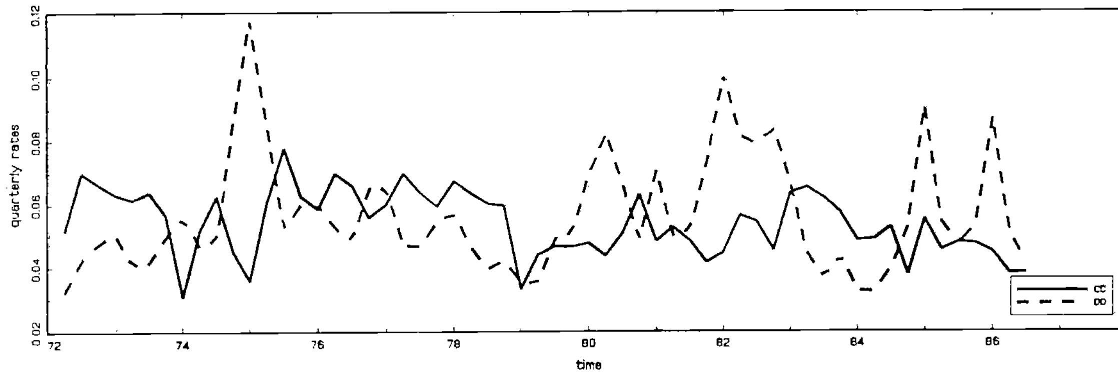


Figure 3b: Index of Industrial Production (Rate of Growth)

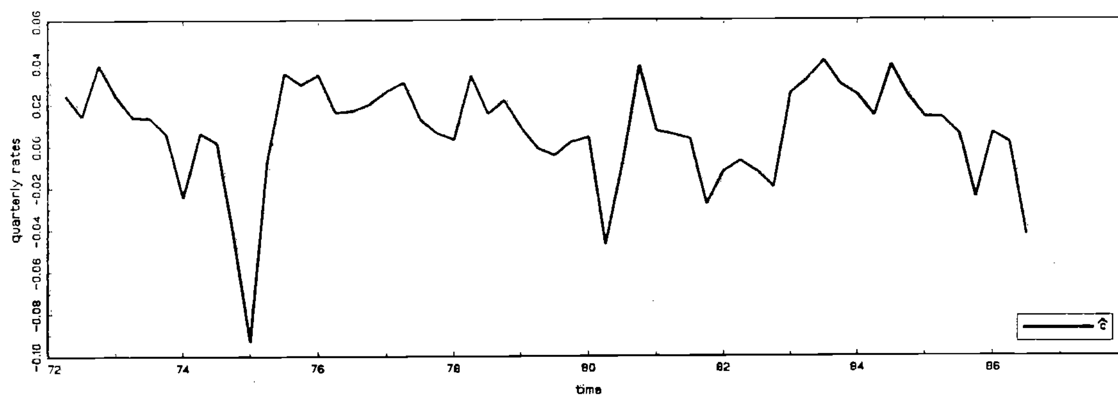


Table 1: Job Creation and Destruction Response to Output Growth

		Creation		Destruction	
		Coefficient	St.Deviation	Coefficient	St.Deviation
$\hat{Q}$	2 Leads	0.029	(0.006)	0.030	(0.010)
	1 Lead	0.065	(0.007)	-0.068	(0.010)
	Contemp.	0.108	(0.007)	-0.185	(0.010)
	1 Lag	0.013	(0.007)	-0.103	(0.010)
	2 Lags	0.003	(0.006)	-0.058	(0.010)
	Sum	0.218	(0.013)	-0.384	(0.017)
$\hat{Q}^+$	2 Leads	0.052	(0.012)	0.012	(0.016)
	1 Lead	0.102	(0.012)	0.002	(0.016)
	Contemp.	0.131	(0.012)	-0.065	(0.016)
	1 Lag	0.059	(0.012)	-0.025	(0.016)
	2 Lags	0.055	(0.012)	-0.008	(0.016)
	Sum	0.399	(0.026)	-0.066	(0.023)
$\hat{Q}^-$	2 Leads	0.002	(0.010)	0.006	(0.014)
	1 Lead	0.022	(0.011)	-0.149	(0.014)
	Contemp.	0.093	(0.012)	-0.293	(0.015)
	1 Lag	-0.012	(0.012)	-0.139	(0.015)
	2 Lags	-0.021	(0.012)	-0.059	(0.015)
	Sum	0.084	(0.020)	-0.634	(0.024)

Note: This table shows the response of job creation and job destruction to changes in the growth rate of the detrended index of industrial production for each sector ($\hat{Q}$), and to the latter split into values above and below its mean ($\hat{Q}^+$ and $\hat{Q}^-$, respectively). The data are quarterly observations for the 2-digit SIC manufacturing industries, for the period 1972:2–1986:4. The coefficients are constrained to be equal across all sectors, except for a constant (not shown).

The first block ($\hat{Q}$) in table 1 presents results from the regression of sectoral rates of job creation and job destruction on leads and lags of the corresponding rates of growth of the indices of industrial production. The first result that arises is that the rate of job destruction is more responsive to changes in sectoral activity than the rate of job creation (the sum of coefficients is -0.384 and 0.218, respectively). This can be seen directly from figure 3, and is one of the key findings in Davis-Haltiwanger (1990, 1991) and Blanchard-Diamond (1990). In terms of our model, the insulating effect of job creation seems far from complete. As can be seen in the simulated example in figure 2, our model can easily match the fact that destruction is more responsive than creation. Of course, this interpretation depends on costly speed of adjustment $c'(f(0,t)) > 0$. But our calibration exercise below shows that a very small elasticity of creation costs — less than 0.08 — is enough to explain the facts.

The second block in table 1 ($\hat{Q}^+$, $\hat{Q}^-$) in the table splits the right-hand side regressors between periods in which the rates of growth of sectoral output are above their mean and periods in which they are below it. Looking first at job creation, we find that it is more responsive to expansions in sectoral activity than to contractions (the sum of coefficients for $\hat{Q}^+$ and $\hat{Q}^-$ are 0.399 and 0.084, respectively). Going back to figure 3, this corresponds to the fact that job creation is roughly symmetric around its mean, while output growth is highly asymmetric with recessions that are shorter lived but much sharper than expansions. It is not surprising, then, that our regression yields an asymmetric response of job creation to expansions and recessions.

If we turn to job destruction, we find quite the opposite effect, with a sum of coefficients that is substantially larger (in absolute value) for recessions than it is for expansions (-0.587 vs. -0.103). Asymmetries in output are thus not only preserved in the response of job destruction (which would hold if the sum of coefficients was symmetric), but are actually amplified.

The fact that asymmetries in demand are smoothed out in the response of job creation and amplified in the response of destruction matches our model's predictions very well. To show this, we simulated a periodic equilibrium with the *asymmetric* process for demand $\dot{D}$ depicted in figure 4.[17] It is clear that the creation process is roughly symmetric, while destruction is highly asymmetric. Intuitively, firms use predictions of future demand in trying to smooth job creation, thus the asymmetries in demand are smoothed out by the

[17]This process was generated with the equation $\dot{D}(t) = 0.05(\cos(t)+\sin(t)) - 0.016\ \sin(2t) - 0.003\ \cos(3t)$. The initial level is set to $D(0) = 1$, and model parameters are set to $r = 0.065$, $\delta = 0.15$ and $\gamma = 0.028$.

Figure 4a: Creation and Destruction
c_0=0.3 c_1=1.0

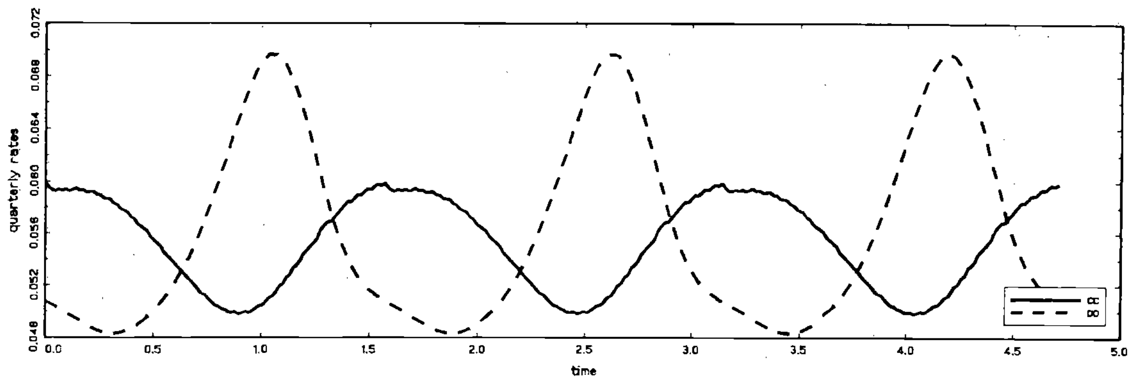
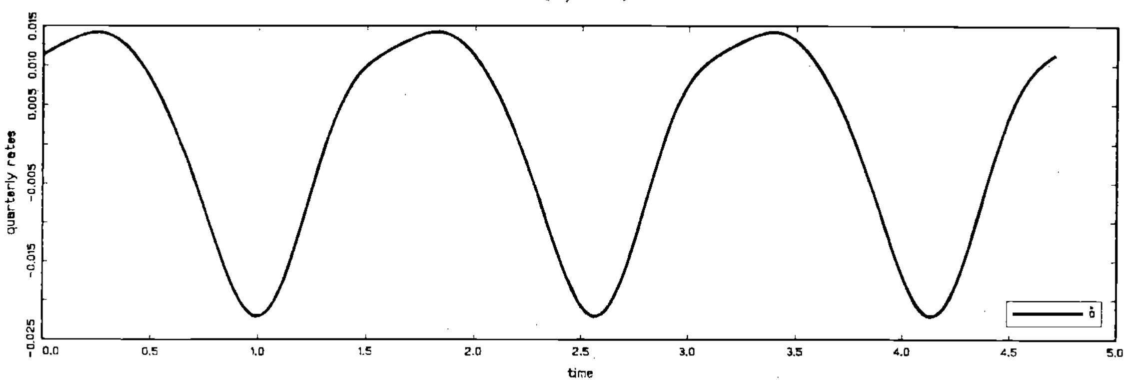


Figure 4b: Change in Demand
(Asymmetric)



averaging of demand over the unit's lifetime. On the other hand, destruction depends only on current conditions, thus asymmetries are reflected directly on it. Moreover, if creation declines only mildly in response to a sharp contraction, the equilibrium price falls more sharply, which induces additional destruction. This is the reason why destruction does not only preserve, but *amplifies* the asymmetries in demand; it must "make up" for the symmetry in creation.

4.2 Calibration Exercise

We now present the results of an exercise based on aggregate manufacturing series that provides a synthesis for the previous discussion. We calibrate the model and use it to generate the equilibrium job creation and destruction series that are consistent in theory with the observed path of employment. In other words, we use the model to split observed net changes in employment into their gross creation and destruction components. We then repeat the exercise using the observed path of output and compute the creation and destruction series that are consistent in theory with the path of demand implied by observed output movements. In both cases, the model-generated series are compared with actual observations.

Solving for an equilibrium requires an initial age distribution of jobs, and expectations of what demand would be after the end of the sample period. We handle this problem by solving for a *periodic* equilibrium, with a period equal to the sample period. The model's response was simulated for the period 1972:2-1983:4 using the method described in the appendix.[18]

In calibrating the model we chose a yearly interest rate $r = 6.5\%$ and a depreciation/failure rate $\delta = 15\%$. To choose the rate of technical progress γ, we approximated trend values by averages over the sample. Since there was very little growth in manufacturing employment over the sample period —and one can easily show the direct link between demand and employment growth— we attributed all of the average growth rate of output to technical progress, and set $\gamma = 2.8\%$.

[18]Although the Davis-Haltiwanger job flow series extend to 1986:4, we chose a shorter period for three reasons: (1) Numerical problems get worse as the simulation period gets longer; (2) Because we are solving for a periodic equilibrium, we need demand to be at roughly the same level at the beginning and at the end of the period; (3) Our model has little to say about the behavior of job destruction in 1985–86, which exhibits two sharp peaks that are not associated with much action on the demand side (see figure 3).

Table 2: Calibrated Parameters

VARIABLE	SYMBOL	VALUE
Interest rate	r	0.065
Depreciation rate	δ	0.150
Rate of technical progress	γ	0.028
Adjustment cost parameters	c_0	0.476
	c_1	0.200

While our results are not very sensitive to the above parameters, they strongly depend on the parameters c_0 and c_1 of the adjustment cost function (11). These parameters were chosen as follows. First $\bar{a}^*$ was calibrated based on equation (9), which relates the steady-state lifetime of jobs to job turnover CC^*. Using the average value of CC over the sample for CC^*, we find that $\bar{a}^* = 7.42$ years. This, together with the parameter values above, allows us to calculate from (7) the present discounted value of profits a production unit can generate in steady state. By the free entry condition this must be equal to the steady-state creation cost, and is found to be equal to $c^* = 0.525$. This leaves us with only one free adjustment cost parameter, since c_0 and c_1 are related in steady state to c^* by (11):

$$c^* = c_0 + c_1 f^*(0),$$

where $f^*(0)$ is given by equation (8). Numerical difficulties prevented us from obtaining results for very small values of c_1. Because the fit of our simulations was best for the lowest value of c_1 we have so far been able to obtain results with, we set c_1 to this value, 0.2.[19] Table 2 summarizes the values we use.

An issue we faced in the output-driven simulation concerned the observed procyclicality of average labor productivity, which our basic model is not designed to explain. To capture this, we introduced an output externality along the lines discussed in section 3.2, and set

[19] Note that our fit would not improve indefinitely as c_1 goes to zero, because in the limit the insulation effect is complete and job destruction does not respond to demand.

the externality parameter β equal to 0.18 (see Caballero and Lyons 1990). Note, however, that our particular interpretation of procyclical productivity is not crucial here, since all it amounts to is dampen the output fluctuations used to drive the simulation by a factor of β. The employment-driven simulation is unaffected.

The results of the employment-driven and output-driven simulations are given and compared to the data in figures 5 and 6.[20] Job creation appears too smooth compared to the data, but this is partly due to the numerical problem when trying to solve the model for values of c_1 lower than 0.2, which would have increased the volatility of job creation. It may also be partly due to the absence of uncertainty in our model. But in general the model can clearly account for the relative volatility of job creation and destruction, and for the greater symmetry of the former compared to the latter.

5 Concluding Remarks

This paper has examined industry response to demand fluctuations in a vintage model of creative destruction, where the response can take place along two possible margins. We argued that responses to demand fluctuations on the creation margin have an "insulating" effect on existing production units, reducing the sensitivity of the destruction side. The extent to which this happens depends on industry-wide costs of fast creation. Empirically, the model seems to provide a good basis for interpreting the Davis-Haltiwanger data on gross job flows.

The central features in our analysis are heterogeneity across production units and their turnover. Although they arise quite naturally in the context of creative destruction, these features can also appear in other environments. Caballero (1990) discusses a model where two margins arise because of idiosyncratic productivity and demand shocks.

In terms of our model, the fact that job destruction is much more responsive to the business cycle than creation leads to the view that recessions are a time of "cleaning up," when outdated or unprofitable techniques and products are pruned out of the productive system. A related, but distinct idea is the "pitstop" view of recessions, according to which recessions are times when productivity-improving activities are undertaken because of their temporarily low opportunity costs (examples of such theories are Davis and Haltiwanger

[20] Note that the output-driven simulation cannot be expected to capture seasonal movements in observed job flows (which are not seasonally adjusted) because the driving process—industrial production—is seasonally adjusted.

Figure 5a: Job Creation
Employment Driven
c_0=0.476 c_1=0.200

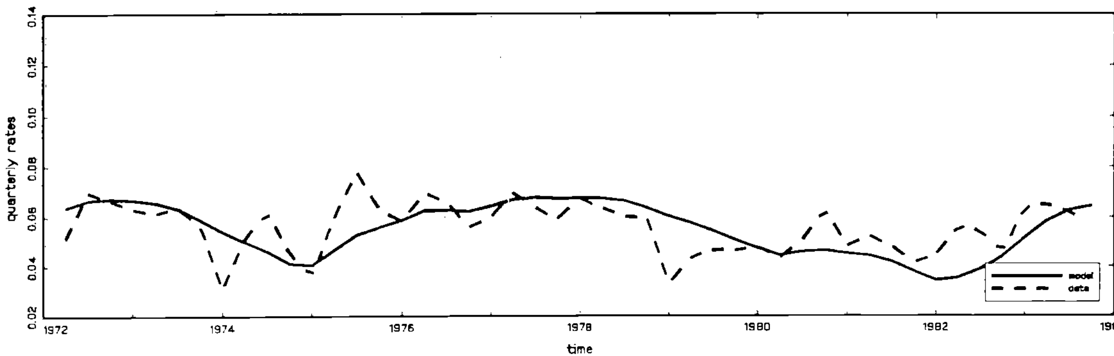


Figure 5b: Job Destruction
Employment Driven
c_0=0.475 c_1=0.200

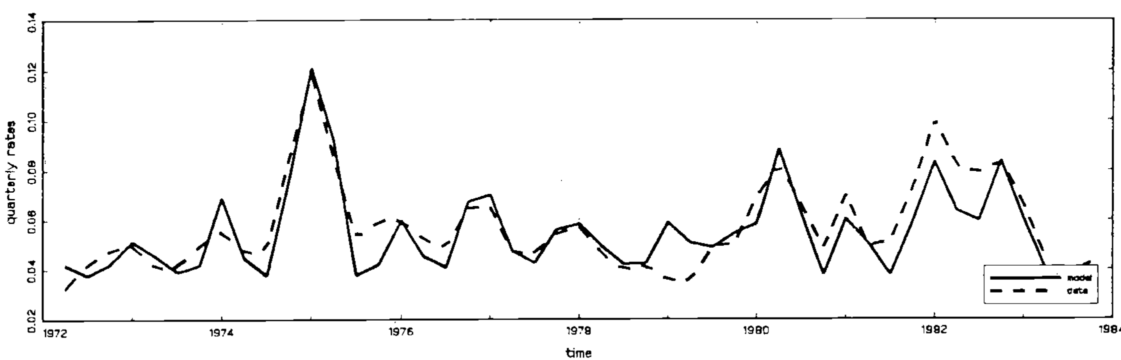


Figure 6a: Job Creation
Demand Driven
c_0=0.476 c_1=0.200

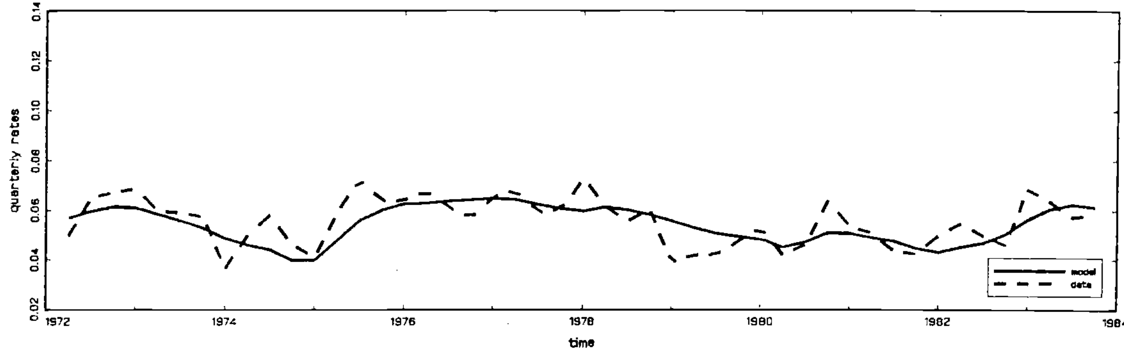
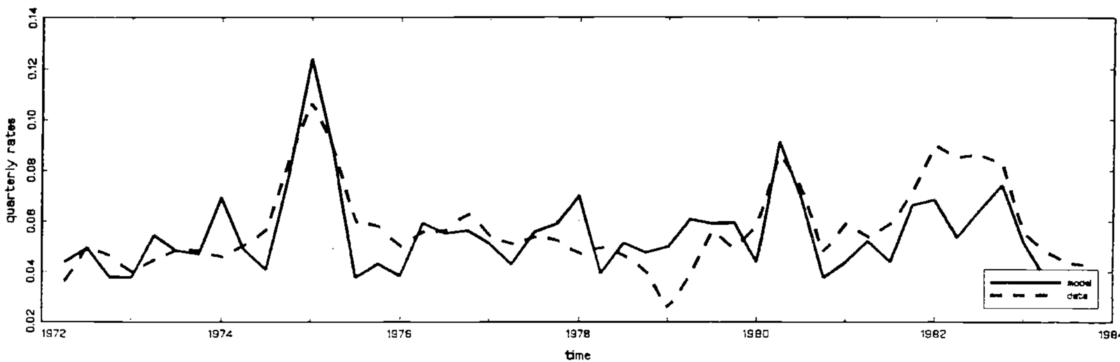


Figure 6b: Job Destruction
Demand Driven
c_0=0.476 c_1=0.200



1990, Hall 1991). One way to integrate both views is to make either creation or destruction costs in our model depend on some aggregate index of economic activity. An interesting implication of two interacting margins arises in this case: One can show that, irrespective of whether it is creation or destruction costs that depend on the aggregate index, the time series implications of both specifications are the same to a first order.

One objection to the view that recessions are times of cleaning up is that it implies countercyclical productivity, while average labor productivity is in fact procyclical. But one can show that this effect on productivity is likely to be small and only operative at lower frequencies. Starting from steady state and using calibrated values for model parameters ($\delta = 0.15$, $\gamma = 0.028$, $\bar{a}^* = 7.4$ years), the effect of destroying 10 percent of the jobs in an industry at the low productivity margin is a mere 1.1 percent improvement in average labor productivity. It will be even smaller relative to trend if accompanied by a fall in the creation rate. This may be dwarfed by other factors (labor hoarding, externalities, etc.) that make measured productivity procyclical. However, as far as the dynamic response of productivity to business cycles is concerned, the evidence has been debated. Although Dickens (1982) argues that recessions leave permanent productivity scars, the more recent paper by Gali and Hammour (1991) finds evidence that recessions improve productivity over the medium-long term.

Several extensions can be introduced without modifying the basic results of the paper. For example, there is evidence that new plants tend to have larger failure rates, which can be easily accommodated in our model by letting $\delta(a)$ be large for small values of a. It is also reasonable to allow for some form of (limited) learning-by-doing. I.e. the productivity level of a production unit created at time t_0 can depend on its age, $A(t_0, a)$, with $0 < A_a(.,.) < \gamma$. And it is obvious that not all production units of the same cohort turn out to be equally successful; which amounts to specify a productivity function $A(t_0, z)$, where z is an index of productivity within a cohort with some distribution $f(z)$.

There are also dimensions of the model that can be explored more fully. For example, one could examine the above-mentioned implications for productivity in more detail, and develop the model's growth-cycle implications more fully. In particular, business cycles may in turn affect the rate of technical progress; and variations in the rate of technical progress itself may be responsible for some aspects of the business cycle (e.g. De Long 1990). Another avenue of research which we are currently exploring is the model's implications for search unemployment. In this context, we conjecture that a fall in demand may have a more severe impact on the unemployment rate if accommodated by a rise in job destruction, than if accommodated by a fall in creation. Moreover, the upward slope of the creation cost curve can be related directly to decreasing returns to vacancy posting in the matching function.

APPENDIX

This appendix describes our method of computing the equilibrium path of model (1)-(6), given a periodic path for demand.

Let $\phi(t) \equiv f(0,t)$. Differentiating (4) and (6) with respect to time, taking (1), (2) and (5) into account, yields

$$\dot{\bar{a}}(t) = 1 + \frac{\dot{\bar{D}}(t) + \delta \bar{D}(t) - e^{\gamma \bar{a}(t)}\phi(t)}{\gamma \bar{D}(t) + \phi(t - \bar{a}(t))e^{-\delta \bar{a}(t)}}; \qquad (A1)$$

$$\dot{\phi}(t) = \frac{1}{c_1}\left[(r + \delta + \gamma)(c_0 + c_1\phi(t)) - (e^{\gamma \bar{a}(t)} - 1) + \gamma \frac{1 - e^{-(r+\delta)T(t)}}{r + \delta}\right]; \qquad (A2)$$

where $\{T(t)\}$ is related to $\{\bar{a}(t)\}$ through equation (3):

$$\bar{a}(t + T(t)) = T(t). \qquad (A3)$$

The differential system $(A1) - (A3)$ has several interesting but complex features. First, equation $(A1)$ for $\dot{\bar{a}}(t)$ includes the second variable $\phi(t - \bar{a}(t))$ delayed. Second, this delay is not only flexible but depends on $\bar{a}(t)$. Third, equation $(A2)$ for $\dot{\phi}(t)$ includes $T(t)$, which by $(A3)$ is a flexible lead that depends on $\bar{a}(t)$.

In order to solve this system we limit ourselves to the case of a periodic driving force $\bar{D}(t)$, with period R. Our algorithm calculates at each iteration i a one-period path $X_i \equiv \{\phi_i(t), \bar{a}_i(t)\}_{0 \leq t < R}$ of creation and destruction, *given* a history of past creation $H_i \equiv \{\phi_i(t)\}_{t<0}$ and expected lifetimes $E_i \equiv \{T_i(t)\}_{0 \leq t}$. With the given history and expectations, system $(A1) - (A2)$ can be sloved forward for any initial values for $(\phi(0), \bar{a}(0))$. Using a multiple-shooting procedure, X_i is chosen to be a "periodic" solution for $(A1)-(A2)$, in the sense that

$$(\phi_i(0), \bar{a}_i(0)) = (\phi_i(R), \bar{a}_i(R)).$$

The algorithm proceeds as follows:

- *Initialization:* Set $i = 1$ and the initial history H_1 and expectations E_1 to arbitrary values (e.g. their steady-state values for an average level of demand $\bar{D}^*$).
- *Iteration i:* Generate the one-period solution X_i, given H_i and E_i.

  If $i > 1$ and $|X_i - X_{i-1}|$ is less than some small ϵ, the procedure has converged. Use X_i as the equilibrium solution and terminate the algorithm.

Otherwise, calculate H_{i+1} and E_{i+1} for the next iteration by extending the "periodic" fucntion X_i to the whole real time interval. H_{i+1} is set equal to the resulting periodic history of $\phi(t)$, and E_{i+1} is obtained from the periodic expectation of $\bar{a}(t)$ using equation $(A3)$. Once this is done, increment i and repeat the iteration.

We run the two theoretical simulations in figures 2 and 4 using this method. The employment- and output-driven simulations in figures 5 and 6 were run with the same method, except that equation $(A1)$ was modified so that we can take output and employment as given, rather than demand. The results in figures 5 and 6 are rather preliminary, because we have not yet taken the time-consuming iterative convergence procedure far enough.

For the employment-driven simulation, equation $(A1)$ was modified as follows. Since the path of $N(t)$ is taken as given, we rewrite $(A1)$ in terms of employment. Recalling the expression

$$\dot{N}(t) = f(0,t) - [f(\bar{a}(t),t)(1 - \dot{\bar{a}}(t)) + \delta N(t)]$$

derived in section 2.1, we get

$$\dot{\bar{a}}(t) = 1 + \frac{\dot{\bar{N}}(t) + \delta\bar{N}(t) - \phi(t)}{\phi(t - \bar{a}(t))e^{-\delta\bar{a}(t)}}. \qquad (A1')$$

We replace $(A1)$ by $(A1')$ and use the solution method described above.

As for the output-driven simulation, recall that we introduced an externality β along the lines described in section 2.1. In this case equilibrium conditions (1)-(6) only hold if we substitute $\tilde{Q}(t) \equiv Q(t)/q(t)^{\beta}$ and $\tilde{P}(t) \equiv P(t)q(t)^{\beta}$ for $Q(t)$ and $P(t)$, respectively, where $q(t) \equiv Q(t)/A(t)$. In other words, by (5), we need to dampen observed output fluctuations $\widehat{Q}(t)$ (where a "hat" designates a growth rate) by a factor of β and use

$$\widehat{\tilde{Q}}(t) = \widehat{Q}(t) - \beta(\widehat{Q}(t) - \gamma).$$

With this in mind, we rewrite $(A1)$ in terms of "dampened" output. The latter is related to demand through equations (5) and (6):

$$\bar{D}(t) = \tilde{Q}(t)e^{-\gamma(t-\bar{a}(t))},$$

where units were chosen so that $A(0) = 1$. Replacing for $\bar{D}(t)$ and $\dot{\bar{D}}(t)$ in (A1) and rearranging, we get

$$\dot{\bar{a}}(t) = 1 + \frac{(\dot{\tilde{Q}}(t) + \delta\tilde{Q}(t))e^{-\gamma t} - \phi(t)}{\phi(t - \bar{a}(t))} e^{(\gamma+\delta)\bar{a}(t)}; \qquad (A1")$$

We replace $(A1)$ by $(A1")$ and solve.

Note that to run these simulations in continuous time, we need a continuous path for $N(t)$ and $Q(t)$, whereas the observed path is discrete. To handle this problem, we regress the growth rates of these two series on as many $\sin(i\omega t)$ and $\cos(i\omega t)$ terms, $i = 1, 2, \ldots$, as we have degrees of freedom, where $\omega \equiv 2\pi/R$. We use the resulting continuous and periodic representation to run the simulations.

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