NBER WORKING PAPER SERIES

A GENERAL MODEL OF DYNAMIC LABOR DEMAND

Daniel S. Hamermesh

Working Paper No. 3356

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
May 1990

This paper is part of NBER's research program in Labor Studies. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

NBER Working Paper #3356
May 1990

A GENERAL MODEL OF DYNAMIC LABOR DEMAND

ABSTRACT

This study derives and estimates a dynamic model of factor demand that includes both fixed and quadratic variable costs of adjustment. Using quarterly data on the employment of mechanics at seven airlines, it finds that both types of adjustment costs characterize the dynamic constraints facing employers. Using monthly data covering production-worker employment in seven manufacturing plants, it shows that only fixed costs are important. The apparent diversity of the underlying costs of adjustment means it is difficult to draw useful inferences from macroeconometric estimates. It suggests the importance of examining broader arrays of microeconomic time series describing labor demand.

Daniel S. Hamermesh
Department of Economics
Michigan State University
East Lansing, MI 48824
(517)355-7349

I. Introduction

Until recently all empirical work on the dynamics of labor demand maintained the underlying assumption of convex variable costs of adjusting inputs of labor. This assumption was never tested; nonconvex variable costs or fixed adjustment costs were never considered. Rather, researchers used the underlying assumption as a basis for inferring the importance of the convexity and the size of the variable costs that underlay the aggregate time-series estimates they produced.

In Hamermesh (1989) I specified an empirical model in which there are no variable costs of adjusting labor demand, but in which the firm incurs a fixed cost whenever it changes its employment level. This model was estimated on a set of monthly time series characterizing individual manufacturing plants. It described employment adjustment in those data better than the distributed lag models implied by the assumption of convex variable adjustment costs.

While those estimates clearly demonstrate that lagged employment adjustment does not universally stem from convex variable costs, they have three difficulties that are rectified in this study. Most important, the model could not allow for the possible presence of both fixed and quadratic variable costs of adjustment. Second, the forcing variable in that study was expected output; there were no data on the price of labor services. Finally, only one set of data was used, so that the novel results may just apply to the one company that was studied. In this study all three difficulties are rectified. Using both the original set of data and a new one that contains information on wages, I derive, specify and estimate a general model of which the conventional model of convex adjustment costs, and the new model of fixed adjustment costs, are special cases. The results indicate the complexity of the process of employment adjustment and of the underlying structure that generates observed paths of labor demand in response to demand and cost shocks.

II. Theoretical Motivation

In this section I outline a model of employers' behavior that is the minimum necessary to generate employment dynamics under generalized adjustment costs. Consider a firm that takes the product price and wage rate as given. Write the concentrated production function as $Q = F(L)$, where L is the labor input. The firm's static profit function is $\pi(L)$, with $\pi' > 0$, $\pi'' < 0$, and $\pi'(L^*) = 0$, where L^* is the long-run profit-maximizing labor demand. In the theoretical derivation I assume that the firm has static expectations about the future paths of product and factor prices.

Employers can face two different kinds of costs should they choose to vary the level of employment.[1] The first is the variable cost of changing employment. Since I focus on net adjustment costs because I concentrate on employment levels, these can be viewed as stemming from increasing disruptions on the plant floor as additional changes in employment levels occur. Without loss of generality I make the standard assumption that the variable costs of adjusting labor demand are quadratic in the size of the adjustment.

Fixed costs may also affect the process of adjusting employment. These costs arise if, for example, changing from one technology to another engenders a disruption to output that is independent of the size of the change. Such a disruption could stem from worker dissatisfaction over changes in staffing, or from the necessity of operating with fixed, lumpy combinations of labor and capital.

I assume that both fixed and variable adjustment costs are symmetric in the direction of the change.[2] The adjustment cost function is then:

$$C(\dot{L}) = a\dot{L} + g\dot{L}^2 + \begin{cases} k \text{ if } |\dot{L}| > 0 \\ 0 \text{ if } \dot{L} = 0 \end{cases} .$$

where the superior dot denotes the rate of change, and a, g and k are parameters of the adjustment cost function. To simplify the analysis of the firm's optimal path, characterize its discounted stream of profits as:

$$(1) \qquad Z = \int_0^T [\pi(L) - a\dot{L} - g\dot{L}^2 - k]e^{-rt}\, dt + \frac{\pi(L_T)e^{-rT}}{r} ,$$

where $0 \leq T \leq \infty$ is the point when the firm stops adjusting labor demand in response to the shock that occurred at $t = 0$; the wage rate w and the product price p are implicit in the function π, and L_T is the value of L that is chosen at the endogenous time T. The employer wishes to maximize (1) subject to the initial condition $L(0) = L_0$. For purposes of exposition I assume arbitrarily that the cost/price shock is such as to increase L^* above L_0.

In the general case a, g, k > 0. The solution is described by the Euler equation (that characterizes the motion of L <u>if</u> L is changing):

$$(2) \qquad 2g\ddot{L} - 2gr\dot{L} + \pi'(L) - ra = 0; \; L(0) = L_0, \; L(T) = L_T ,$$

and by the additional conditions:

$$(3) \qquad -2g\dot{L}_T - a + \frac{\pi'(L_T)}{r} = 0 ,$$

and:

$$(4) \qquad -g\dot{L}_T^2 - a\dot{L}_T + \frac{\pi'(L_T)\dot{L}_T}{r} - k = 0 .$$

The nature of the solution depends on the relative sizes of the parameters a, g, k, the discount rate r, and the structure of the profit function π. Condition (2) is the standard equation of motion for adjusting factor demand (though in the standard case $T \rightarrow \infty$ and $L_T \rightarrow L^*$). Condition (3) states that the present value of the marginal profits from changing L_T, the level of L chosen at the point when the firm stops changing L, must equal the marginal adjustment cost of that increase. Condition (4) is that the present value of the increased profits from raising T must equal the increased cost of adjustment.

Taken together, conditions (2)-(4) imply a path along which the firm does not adjust labor demand if the shock is relatively small. If the shock is large enough, though, labor demand will adjust smoothly toward L^*; but the firm will stop changing its labor input before L^* is reached. The motion of L is shown in Figure 1, under the assumption that employment has been shocked away from its long-run equilibrium L^*. If the shock is sufficiently large so that $L_0 > L^*_+$ or $L_0 < L^*_-$, employment begins to adjust smoothly toward the target, L^*. Once employment reaches L^*_+ (L^*_- if the shock is negative), L ceases changing. The existence of fixed costs of adjustment that must be borne in each period during which employment is changing creates a zone of indeterminacy around the long-run equilibrium employment level L^*.[3]

The comparative dynamics of the system (2)-(4) can be analyzed to show the effects of changes in the underlying parameters. Equation (4) is a quadratic in $\dot{L}_T$. It has real roots only if:

$$\left[\frac{\pi'(L_T)}{r} - a\right]^2 \geq 4gk \ .$$

Since we know that $\pi'(L^*) = 0$, and since both g and k are positive in general, this condition means that general $L_T \neq L^*$. Rewriting and substituting in (3):

$$(3') \quad \dot{L}_T \geq \left[\frac{k}{g}\right]^{.5} ,$$

and

$$(4') \quad \pi'(L_T) \geq 2r[gk]^{.5} + ar.$$

With a shock that raises L^*, equation (3′) shows that an increase in k raises the rate of adjustment at the terminal point. Equation (4′)

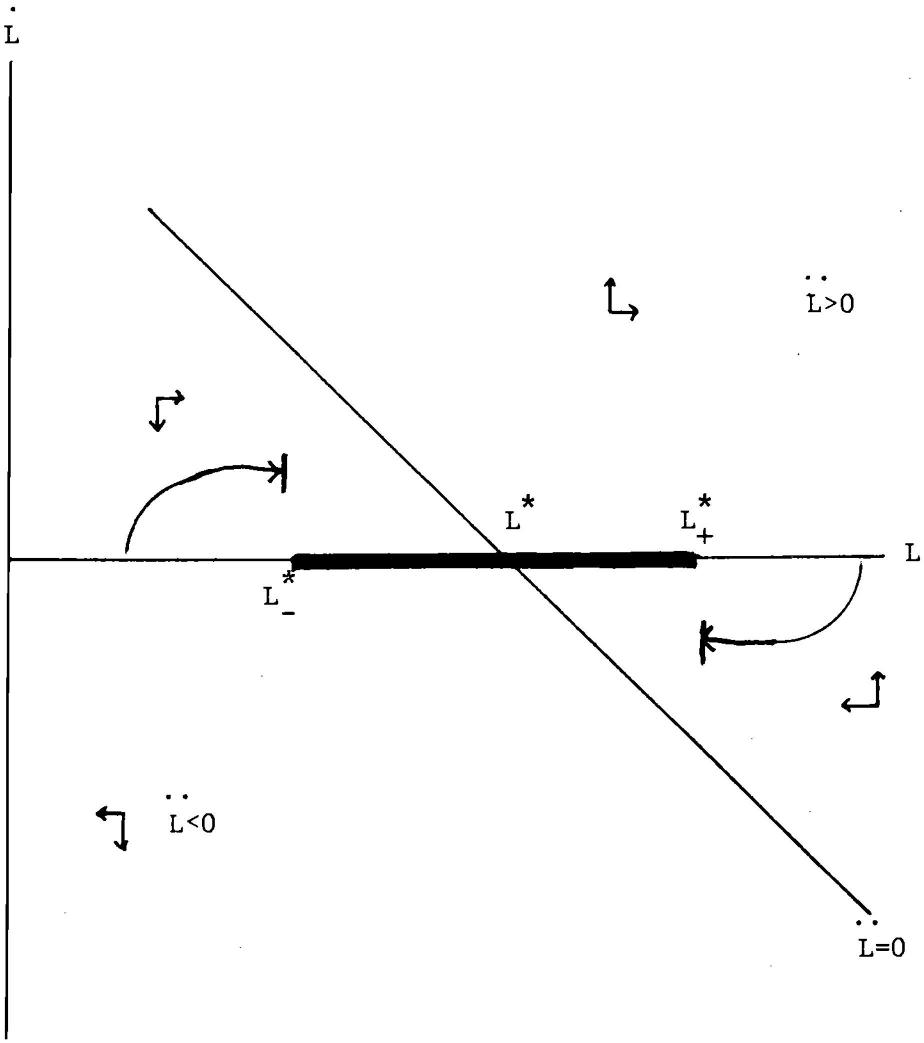

Figure 1. Dynamics with Fixed and Variable Adjustment Costs

shows that, as k increases, the slope of the profit function at the terminal point increases. Together they imply that higher fixed costs of adjustment increase the gap between L_T and L^* and reduce T. In terms of Figure 1 they increase the horizontal distance along the heavy line $[L^*_-, L^*_+]$. An increase in g reduces the rate of adjustment at T but increases the slope of the profit function at the terminal point. Together these imply that increased g raises the gap between L_T and L^*, but that it takes longer for the firm to adjust to L_T. An increase in a has no effect on the rate of adjustment at T, but it reduces L_T. (It reduces L^* by an equal amount, so it has no effect on the length of the heavy line in Figure 1.) Finally, increased r reduces L_T.

If there are no fixed costs, $L_T = L^*$, and the standard solution applies. The firm moves smoothly back to its long-run equilibrium at L^*. If there are no variable costs, or if those costs are only linear, the firm either makes a discrete change by setting employment at L^*, or leaves employment at L_0 if the costs of the discrete change exceed the present value of the extra per-period profits that are generated at L^*.

III. An Empirical Representation

To represent the general theoretical model empirically, let us abandon the assumption of static expectations and assume instead that the firm forecasts the path of future demand shocks rationally as $E_t X_{t+i}$, i = 1, 2, ..., where X is a vector of forcing variables in a behavioral relation describing the demand for labor. If the firm is not on the ray $[L^*_-, L^*_+]$, we can describe L_t, observed employment, as:

(5) $$L_t = \gamma L_{t-1} + [1-\gamma]E_t\sum_{i=0}^{\infty}X_{t+i}[1+r]^{-i} + \mu_{1t}, \quad \left|L_{t-1} - E_t\sum_{i=0}^{\infty}X_{t+i}[1+r]^{-i}\right| > K + B\gamma.$$

I assume $1 > \gamma \geq 0$ and that μ_{1t} is a disturbance with mean zero and variance $\sigma^2_{\mu_{it}}$. The parameter γ is correlated with the size of the quadratic term in the variable costs of adjustment. K is a measure of the fixed costs of adjustment. The parameters K, B and γ determine the relative size of the ray $[L^*_-, L^*_+]$. They are included in the switching condition in (5), for the theory indicated that both k and g affected the length of the ray $[L^*_-, L^*_+]$. Each is separately identifiable because γ is included by itself in the equality in (5).

Ignoring the switching condition that determines whether or not the firm changes employment, (5) is the same geometric lagged adjustment mechanism that has become standard in the literature on dynamic factor demand (Nickell, 1986). The firm adjusts employment toward a moving target determined by its expectations about the future paths of the forcing variables. In this general model, though, it stops some measurable distance before reaching that moving target because of the presence of fixed adjustment costs.

Let expectations about the vector X be represented by:

(6) $$E_t \sum_{i=0}^{\infty} X_{t+i}[1+r]^{-i} = \sum_{j=1}^{N} \alpha_j X_{t-j} + \epsilon_t ,$$

where the α and ϵ are respectively vectors of parameters and i.i.d. disturbances. If X contains M forcing variables, the right-hand side of (6) can be rewritten as $\sum_{m=1}^{M} (\sum_{j=1}^{N} \alpha_j X_{t-j} + \epsilon_{mt})$, where the X are the variables in the vector X, each α_j is a vector of length M, and the ϵ are disturbance terms. Recognizing that the ϵ_{mt} cannot be separately identified, I assume that $\sum_m \epsilon_{mt} = \epsilon_t$, which I assume is distributed normally with mean zero and variance σ^2_ϵ. Using (6) we can then rewrite (5) as:

$$(5') \quad L_t = \gamma L_{t-1} + [1-\gamma]\{\sum_{m=1}^{M} \sum_{j=1}^{N} \alpha_j X_{t-j} + \epsilon_t\} + \mu_{1t}, \quad \left| L_{t-1} - \sum_{m=1}^{M} \sum_{j=1}^{N} \alpha_j X_{t-j} - \epsilon_t \right| > K + B\gamma.$$

The firm implicitly assesses the available information on the vector Ξ at the start of period t, assesses the previous period's value of L, then decides whether to alter L during period t.

If the firm is on the ray $[L^*_-, L^*_+]$, I assume that it attempts to hold employment constant:

$$(7) \quad L_t = L_{t-1} + \mu_{2t}, \quad \left| L_{t-1} - \sum_{m=1}^{M} \sum_{j=1}^{N} \alpha_j X_{t-j} - \epsilon_t \right| \leq K + B\gamma,$$

where μ_{2t} is again a disturbance with mean zero. In this case the expected long-term gain from changing employment is insufficient to overcome the fixed and variable adjustment costs. If $B \equiv \gamma \equiv 0$, equations (5′) and (7) reduce to the fixed-cost model of Hamermesh (1989). If $K = B = 0$, equations (5′) and (7) reduce to the standard geometric model of dynamic adjustment under rational expectations about the forcing variables.

Equations (5′) and (7) form a switching model involving the choice variable L_t. In estimating this system I assume that $E(\mu_{1t}\mu_{2t}) = 0$ and that $E(\mu_{1t}\epsilon_t) = E(\mu_{2t}\epsilon_t) = 0$. I assume that $\sigma_{\mu_1} = \sigma_{\mu_2}$. Together these assumptions mean we can treat the μ_{it} terms in (5′) and (7) as both being μ_t. The specification also implies that the variance of the error in (7) is restricted to be less than that in (5′), since the latter is the sum of two independent errors, one of which is the error in (7). Though prompted by a desire to make the estimation problem tractable, this assumption is reasonable. It means that I am assuming that errors in attaining the dynamically optimal level of employment are greater when the firm is trying to change that level than when it is not.

The switching condition depends on the realization of the error term ϵ_t. Rewriting that condition in terms of the error (and using the vector notation for the forcing variables) implies that the firm will attempt to vary employment if:

$$\epsilon_t > K + B\gamma + [L_{t-1} - \sum_{j=1}^{N}\alpha_j X_{t-j}] \ \underline{\text{or}} \ \epsilon_t < -K - B\gamma + [L_{t-1} - \sum_{j=1}^{N}\alpha_j X_{t-j}].$$

It will seek to hold employment constant if:

$$\epsilon_t \leq K + B\gamma + [L_{t-1} - \sum_{j=1}^{N}\alpha_j X_{t-j}] \ \underline{\text{and}} \ \epsilon_t \geq -K - B\gamma + [L_{t-1} - \sum_{j=1}^{N}\alpha_j X_{t-j}].$$

This stochastic specification shows how the observed prior shocks to the forcing variables X and the uncertainties involved in forming expectations reflected in the ϵ_t, may cause the firm to begin to vary the level of employment.

To estimate the parameters in (5′) and (7) --- the α, K, B, γ and the variances σ_μ^2 and σ_ϵ^2, I use the D-method proposed by Goldfeld and Quandt (1976). The probability that employment is being changed (of being on (5′)) is:

$$p_t = 1 - \Phi\left[\frac{K + B\gamma + L_{t-1} - \sum_{j=1}^{N}\alpha_j X_{t-j}}{\sigma_\epsilon}\right] + \Phi\left[\frac{-K - B\gamma + L_{t-1} - \sum_{j=1}^{N}\alpha_j X_{t-j}}{\sigma_\epsilon}\right],$$

where Φ is the cumulative unit normal distribution function (and I have implicitly assumed that ϵ is normally distributed). $1-p_t$ is the probability that the firm tries to hold employment constant at L_{t-1}. The likelihood function for this model is:

$$(8) \quad \mathcal{L} = \prod_{t=1}^{T} g(\mu_t + \epsilon_t)^{P_t} \cdot g(\mu_t)^{1-P_t} ,$$

where $g(\mu_t + \epsilon_t)$ is the density of the error term in (5′) and $g(\mu_t)$ is the density of μ_t from (7). I assume that the error terms μ are also normally distributed. The estimation involves maximizing the logarithm of the likelihood function (8).

IV. Data and Preliminary Results

It is impossible to make any inferences about the structure of adjustment costs using spatially aggregated data or even to infer their magnitude (Hamermesh, 1990). The model described by (5′) and (7) must be estimated using data describing microeconomic units. Accordingly, I estimate this model using two sets of data. The first, a collection of monthly time series on production-worker employment and production in seven large plants operated by a major manufacturing company, formed the basis for the analysis in Hamermesh (1989). These data allow for 52 observations on employment beginning in February 1983, and additional data on output beginning in 1978. Their advantage is that they are monthly, so that problems of temporal overaggregation are less likely to arise (see Engle and Liu, 1972). Their disadvantages are that the only forcing variables that can be constructed are time trends and measures based on the production data, and that employment adjustment in heavy manufacturing may be highly atypical.

To remedy these difficulties I obtained the data for 1969-76 on the employment of mechanics by seven trunk airlines that were assembled and used by Card (1986). This set of data has the attractive property that it contains wage as well as output measures for use in the vector *X*. It is completely clear that factor prices affect estimates of employment demand (though the larger fraction of variance in employment is due to output shocks (Hamermesh, 1986; Freeman, 1977)) It may thus be important to include wages in the vector *X*. The difficulty with these data is that they are quarterly. This means that the temporal aggregation may reduce our ability to infer the nature of adjustment costs. Also, the short length of the quarterly time series limits the amount of information available for calculating lags in *X*.

An initial, albeit partial view of the process of employment adjustment can be obtained by examining the data on the employment of airline mechanics in relation to the real revenue generated by airline departures in Card's data. These series are shown in Figures 2-8 for the seven airlines. The dotted lines depict real departure revenues, while the solid lines show the employment of airline mechanics. There is some relation between the series, and employment is much smoother than departure revenues. There is not, however, the kind of damped response to each fluctuation in output that is implicit in the standard models of smooth adjustment. Instead, employment often stays constant for several quarters. It appears to fall or rise mainly in response to the larger changes in output, which is consistent with the fixed-cost hypothesis. These employment variations are, though, less pronounced than the fluctuations in output, suggesting either that there are increasing returns to scale, or that employment changes are being smoothed when they occur.

To compare the hypotheses of fixed and quadratic variable adjustment costs formally, I estimated the model in (5′) and (7) on the airline data. One set of estimates restricts $K = B = 0$, and thus specifies the standard geometric lag in employment adjustment that is implied by quadratic variable adjustment costs. The switching model collapses in this case to an equation that is estimable by ordinary least squares.

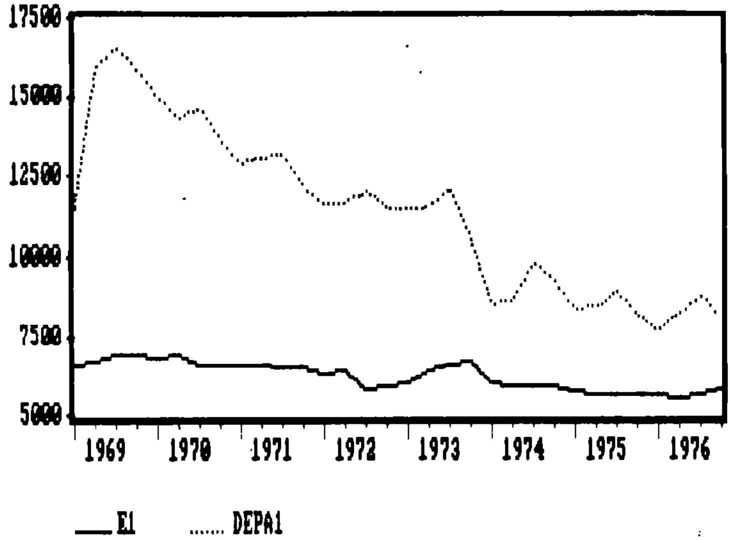

Figure 2. Employment and Departure Revenues, American Airlines

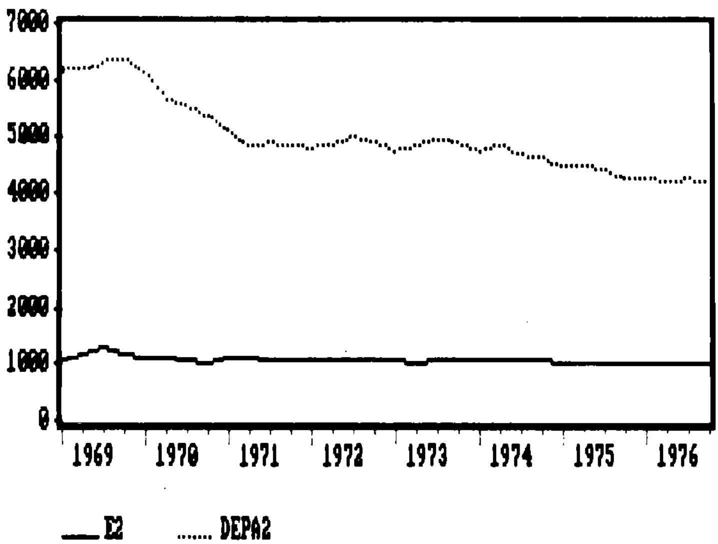

Figure 3. Employment and Departure Revenues, Braniff Airways

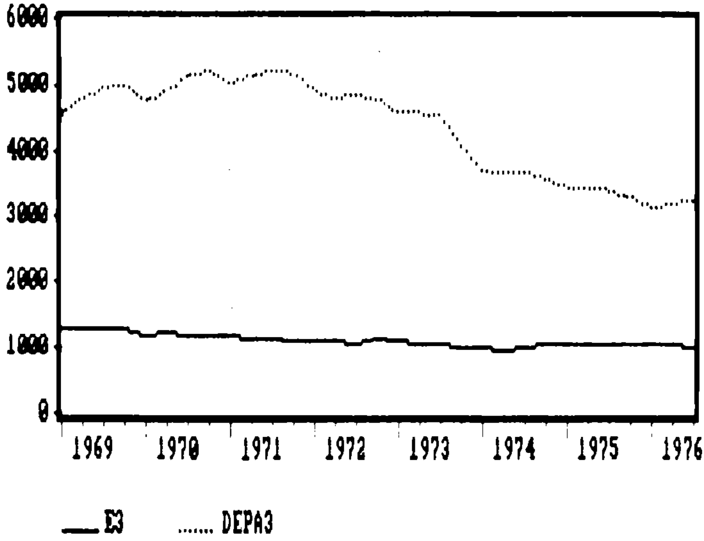

Figure 4. Employment and Departure Revenues, Continental Airlines

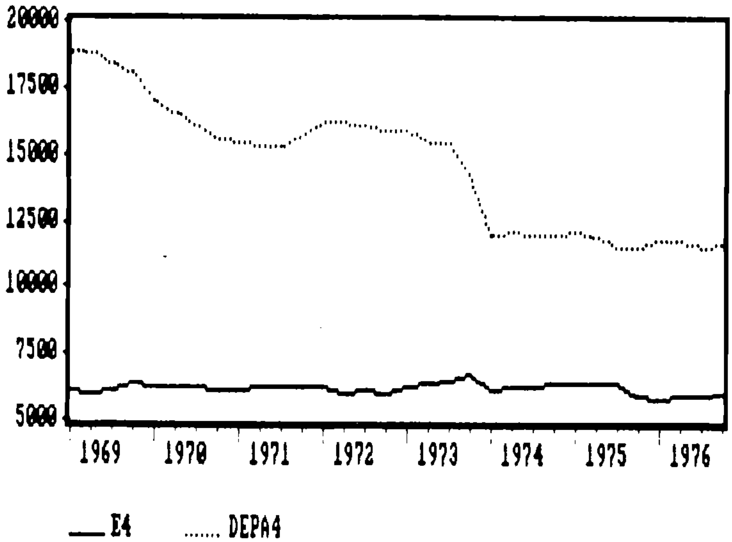

Figure 5. Employment add Departure Revenues, Eastern Airlines

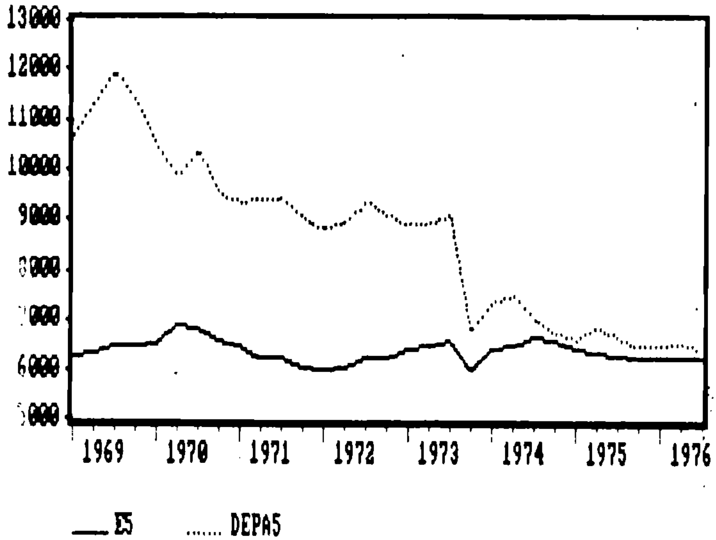

Figure 6. Employment and Departure Revenues, TWA

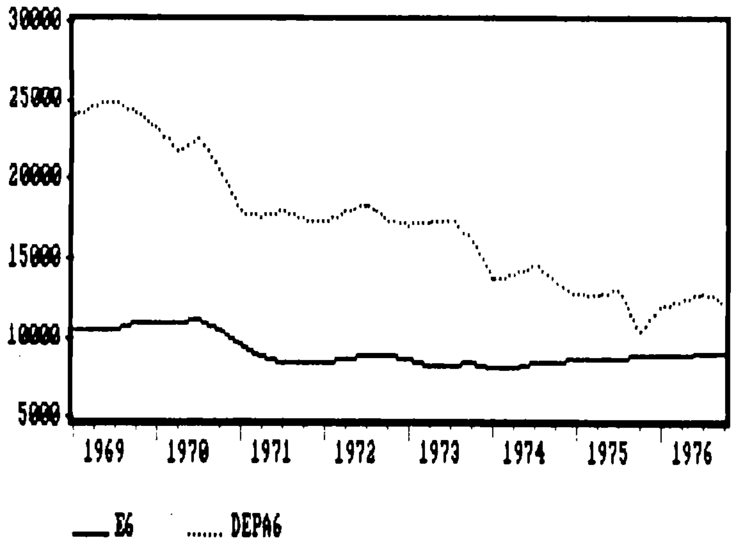

Figure 7. Employment and Departure Revenues, United Airlines

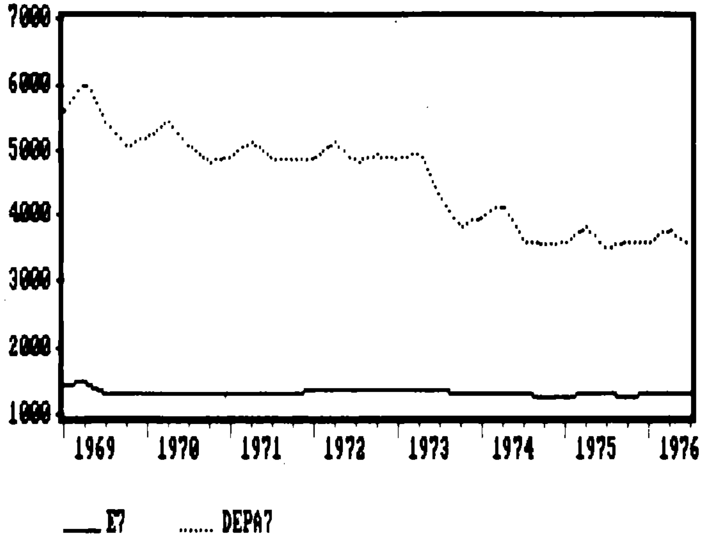

Figure 8. Employment and Departure Revenues, Western Airlines

The other set of estimates restricts $B = \gamma = 0$, thus specifying a switching model in which there are only fixed costs and the firm either attempts to hold employment constant or jumps to a new long-run equilibrium value of employment. Ignoring quits, in this model the switching condition can be viewed as giving the probability that the firm is laying off workers (if $\Delta L < 0$), or rehiring or hiring workers (if $\Delta L > 0$).

The choice of variables to include in X is dictated by the available data and by the length of the time series. Ideally one would like to include sales and prices of several inputs, including wages. Regrettably, only wages and one measure of sales, departure revenues, are available. I assume that expectations about departure revenues and wages are formed based on the previous two quarters' realizations of these series, so that $M = N = 2$ in (5') and (7). To some extent this approach circumvents any possible endogeneity of output, though solid evidence (Quandt and Rosen, 1989) suggests that is not a serious problem. All quantities and prices are measured in logarithms. Also included in the equations is a time trend. In addition to the tests for the individual airlines, the data were pooled (and separate time trends and constant terms were included for each airline).

The quadratic variable cost and fixed-cost models are not nested (though both are nested in the general model of (5') and (7)). However, the latter contains one more parameter than the former, so that a reasonable, though informal test of their relative performance is whether the log-likelihood value for the fixed-cost model exceeds that of the quadratic variable cost model by 2 or more. Consider the log-likelihood values for the restricted models in Table 1. For American, Eastern and TWA the fixed-cost model clearly performs better; for

Table 1. Log-Likelihood Values, Quadratic vs. Fixed-Cost Models, Airlines Data, 1969-76

SAMPLE	MODEL OF ADJUSTMENT COSTS	
	Quadratic	Fixed
Pooled	461.62	475.04
American	68.01	76.89
Braniff	66.96	*
Continental	75.41	71.62
Eastern	74.29	81.31
TWA	68.22	73.69
United	75.33	77.23
Western	91.77	93.07

*Did not converge.

Continental it clearly performs worse, and for Braniff the estimation procedure failed to converge. For United and Western the fixed-cost model yields a higher likelihood, but the difference is not large. Pooling the data on all seven airlines, though, one sees that the fixed-cost model does perform somewhat better.

Unlike in the heavy manufacturing data used in Hamermesh (1989), the quarterly data describing the employment of airline mechanics do not show the clear dominance of the fixed-cost model. On the other hand, they also do not show that employment adjusts smoothly. Instead, the inability to discriminate well between the two models suggests that employment adjustment in this industry may be characterized by both quadratic variable and fixed costs.

V. Estimates of the General Model

In Table 2 I present estimates of three models of the adjustment of employment of airline mechanics between 1969 and 1976. The first column shows the estimates of a standard model in which γ is simply the coefficient on the lagged dependent variable. The second column presents estimates of equations (5′) and (7) with $\gamma = B = 0$, i.e., of a model with only fixed adjustment costs. The third column lists the results of estimating the unconstrained version of (5′) and (7) --- a generalized model of adjustment costs. In this model I estimate γ as $N^{-1}(\gamma')$, where N(.) is the cumulative normal distribution. This specification constrains the lagged adjustment parameter to lie on the unit interval. Included in the estimates of the fixed-cost model are measures of the probability of switching to the new equilibrium and statistics describing that probability over the sample. For the generalized model similar statistics describe the probability that the firms seek to alter their employment of mechanics.

Table 2. Estimates of Three Models of Adjustment, Pooled Airlines Data, 1969-76[a]

Variable[b] or parameter	Quadratic	Fixed	Mixed
	MODEL OF ADJUSTMENT COSTS		
Departure Revenues$_{-1}$	0.205 (.128)	0.243 (.041)	0.773 (.073)
Departure Revenues$_{-2}$	-0.201 (.154)	0.918 (.041)	-0.283 (.060)
Real wage$_{-1}$	0.093 (.134)	-0.637 (.041)	0.044 (.042)
Real wage$_{-2}$	-0.204 (.127)	-0.638 (.041)	-0.403 (.089)
K	0	0.819 (.046)	-1.426 (.110)
B	0	0	1.624 (.087)
γ in col. (1), $N^{-1}(\gamma)$ in col. (3)	0.749 (.048)		1.319 (.052)
σ_μ	0.026	0.025	0.000
σ_ϵ	0	0.010	0.037
log $\mathcal{L}$	461.62	475.04	500.32
Probability of switching or moving:			
Mean		0.004	0.622
Standard deviation		0.019	0.288
Minimum		0.000	0.220
Maximum		0.152	1.000

[a]Standard errors in parentheses below parameter estimates, here and in Table 3.

[b]Equations also include separate constant terms and time trends for each airline.

The first thing to note from Table 2 is that the generalized model describes adjustment far better than either of the two models that are nested in it. Clearly in this industry, and for this group of workers, adjustment is affected both by fixed and by quadratic variable adjustment costs. In this generalized model $\hat{K}$ can take on any value, and for this sample it is negative. The relevant statistic is the estimate of K + Bγ, a measure of the distance $|L_+^* - L^*|$, the range over which the firm will not vary employment. In this sample $\hat{K} + \hat{B}\hat{\gamma} = 0.046$, implying that shocks that are fairly small and that occur when the firm is within five percent of its static profit-maximizing employment level will not cause it to seek to alter employment. Even with quarterly data, and even though the fixed-cost model did not vastly outperform the variable adjustment cost model, estimates of the generalized model imply that there is a substantial range within which firms will not try to change employment. On the other hand, when adjustments are made, employers in this industry find it profitable to adjust slowly rather than discretely.

In the quadratic model in column (1) of Table 2 the implied long-run employment-wage elasticity is -0.44, near the low end of the range found in many other studies (see Hamermesh, 1986). The employment-output elasticity is essentially zero. In the fixed-cost model both elasticities slightly exceed one in absolute value; in the generalized model both elasticities are far above one in absolute value, much larger than is common in the factor-demand literature. In this set of data estimates of these elasticities are quite sensitive to the specification of the adjustment process. One should note, though, that estimates from the generalized model are not true long-run elasticities, and thus not strictly comparable to the estimates from column (1): Since the firm never gets closer to its long-run equilibrium than L_+^* or L_-^*, the long-run elasticity is not a useful concept. Only the short-run responses to changes in wages and in expected output should be considered.

The estimates of the probability of changing employment (adjusting along equation (5′)), p_t, imply that the generalized model is a useful description of behavior. The average probability is slightly above one-half. More important, there is very substantial variation in this probability over the sample, as shown by the range and the large standard deviation of p_t. Unlike the estimates of the fixed-cost model in column (2), where the probability of switching varies only slightly from zero, the generalized model describes movement (or stability) well, in the sense that the data allow the model to discriminate between the two regimes.

To begin examining whether this complex generalized description of adjustment costs is always necessary, I estimated the generalized model on the heavy manufacturing data described above. In this example M = 1, but the presence of information on output for five years before the employment data are available allows more careful modeling of the employer's expectations about output. Rather than using a few lagged values of output, I measure expected output in period t as, ${}_{t-1}Y_t^*$, based on twelfth-order autoregressions of output for each of the seven plants in the sample. To capture the employer's forward-looking projections I also include an extrapolation of changes in expected output over the next three months, ΔY_{t+3}^*, as suggested by Nickell (1984). The forecasts are based on constantly updated regressions over the previous five years of output.[4]

The results of estimating the three models on the pooled data for the heavy manufacturing firm are shown in Table 3. Unlike the case of airline mechanics, we cannot reject the hypothesis that adjustment in this

Table 3. Estimates of Three Models of Adjustment, Pooled Heavy Manufacturing Data, 1983-87

Variable[a] or parameter	MODEL OF ADJUSTMENT COSTS: Quadratic	Fixed	Mixed
Y^*_{t-1}	0.121	0.160	0.165
	(.024)	(.017)	(.016)
ΔY^*_{t+3}	0.031	0.046	0.043
	(.008)	(.012)	(.009)
K	0	0.584	0.540
		(.072)	(.056)
B	0	0	0.068
			(.053)
γ in col. (1)	0.312		-1.335
$N^{-1}(\gamma')$ in col. (3)	(.053)		(.427)
σ_μ	0.501	0.493	0.493
σ_ε	0	0.159	0.133
log $\mathcal{L}$	-262.62	-230.77	-229.94
Probability of switching or moving:			
Mean		0.200	0.173
Standard deviation		0.179	0.272
Minimum		0.045	0.000
Maximum		0.999	1.000

[a]Equations also include a constant term and a time trend.

firm is characterized solely by fixed costs: A test of whether $\gamma = B = 0$ yields $\chi^2(2) = 1.66$, not significantly different from zero. Moreover, the estimate of γ in column (3) is small; and the implied estimate of the range of stability around L^* is $\hat{K} + \hat{B}\hat{\gamma} = .546$, essentially the same as $\hat{K}$ in column (2). A test of the hypothesis that $K = 0$ yields $\chi^2(1) = 45.36$, easily rejecting the notion that there are no fixed costs of adjustment.

The estimate of γ' that is implied by the generalized model, 0.09, is small and is not significantly positive. The responses of employment in the seven plants in this sample to changes in expected output vary only slightly when the lag structure is generalized to include both variable and fixed adjustment costs. In this firm production-worker employment is held constant unless demand shocks are sufficiently large. It is then changed discretely and equated to the expected profit-maximizing value L^*.

Consider some potential biases that the nature of the two sets of data might be imparting to our inferences about the relative importance of the two sorts of adjustment costs. The airline data, though microeconomic in that they cover single firms, are for each airline an aggregate over a number of workplaces at which mechanical work is performed on the airline's fleet. This spatial aggregation will to some extent mask any discrete changes in employment in individual workplaces, as demand shocks average out across workplaces. Similarly, the airline data are more highly aggregated temporally than are the data for heavy manufacturing, so that the discrete responses to shocks may be averaged over time as well. For both reasons the estimates for airlines may understate the importance of fixed costs. Indeed, that the general model suggests the importance of such costs in the airline data is strong evidence for abandoning the standard model of quadratic adjustment costs.

Both sets of data cover unionized employees. We have no theory of what union work rules and wage-setting does to the structure of adjustment costs. It is likely, though, that by increasing formalization in the workplace unions generate greater fixed adjustment costs: Since a collective decision must be made about any layoff, the cost of mass layoffs does not rise as rapidly as in a nonunion setting. For that reason the estimates, while not necessarily biased, may atypically reflect a greater importance of fixed adjustment costs than is true economy-wide.

Unfortunately, neither set of data contains information on hours worked. Without such data we cannot know the extent to which the variations in employment that occur in response to output shocks are cushioned by fluctuations in hours, nor what the structure of the implied costs of adjusting hours is. Ignoring variations in hours may bias the results toward inferring that one type of cost of adjusting employment is relatively more important, but the direction of the bias is not clear.

VI. Conclusions

Using two sets of microeconomic time series, I have estimated a generalized model of adjustment costs that nests both the standard lagged adjustment model (based on quadratic variable costs) and a model of fixed costs of varying employment. Taken together, the results show that both fixed and variable costs must be considered if we are to capture the underlying structure of adjustment costs. The conclusion that fixed costs are important in describing adjustment is not affected by the exclusion of wages from the set of forcing variables. The conclusion is similarly robust to temporal aggregation of microeconomic data up to the quarterly level.

If we wish to predict how changes in policies relating to job security, labor-market intermediation and investment in training will affect employment demand, we need to know the structure of the costs that affect adjustment. If adjustment were generally characterized by quadratic variable costs, the task would be simple. We could just estimate equations describing aggregate employment dynamics and infer the size of the costs facing the representative firm. It clearly is not; nor, as the results here show, is it characterized solely by fixed adjustment costs. The complexity of the dynamic costs of factor adjustment makes using aggregate data inappropriate; and the diversity of the structures of adjustment costs at the firm level presents those seeking to do more than merely predict the path of employment with an arduous but important task.[5] They imply that a wide range of studies of individual firms is required before we will be able to understand the nature of the dynamic costs of labor and to use that knowledge to infer the impact of policies that may alter adjustment costs.

REFERENCES

David Card, "Efficient Contracts with Costly Adjustment: Short-Run Employment Determination for Airline Mechanics," American Economic Review, 76 (1986): 1045-1071.

Russell Davidson and Richard Harris, "Non-Convexities in Continuous-Time Investment Theory," Review of Economic Studies, 48 (1981): 235-253.

Robert Engle and Ta-chung Liu, "Effects of Aggregation over Time on Dynamic Characteristics of an Econometric Model," in Bert Hickman, ed., Econometric Models of Cyclical Behavior, Vol. II. New York: National Bureau of Economic Research, 1972.

Richard Freeman, "Manpower Requirements and Substitution Analysis of Labor Skills: A Synthesis," Research in Labor Economics, 1 (1977): 151-184.

Stephen Goldfeld and Richard Quandt, "Techniques for Estimating Switching Regressions," in Idem., eds., Studies in Nonlinear Estimation, Cambridge, MA: Ballinger, 1976.

Daniel Hamermesh, "Aggregate Employment Dynamics and Lumpy Adjustment Costs," in Carnegie-Rochester Public Policy Conference Series, 33 (1990): forthcoming.

----------------, "The Demand for Labor in the Long Run," in Orley Ashenfelter and Richard Layard, eds., Handbook of Labor Economics, Amsterdam: North-Holland, 1986.

-------------, "Labor Demand and the Structure of Adjustment Costs," American Economic Review, 79 (1989): 674-689.

Stephen Nickell, "An Investigation of the Determinants of Manufacturing Employment in the United Kingdom," Review of Economic Studies, 51 (1984): 529-557.

-------------, "Dynamic Models of Labour Demand," in Orley Ashenfelter and Richard Layard, eds., Handbook of Labour Economics, Amsterdam: North-Holland Press, 1986.

Richard Quandt and Harvey Rosen, "Endogenous Output in an Aggregate Model of the Labor Market," Review of Economics and Statistics, 71 (1989): 394-400.

Michael Rothschild, "On the Cost of Adjustment," Quarterly Journal of Economics, 85, (1971): 605-622.

P. K. Trivedi, "Distributed Lags, Aggregation and Compounding: Some Econometric Implications," Review of Economic Studies, 52 (1985): 19-35.

FOOTNOTES

1. Implicit in this derivation is the assumption that the costs that affect employment adjustment are all on net adjustment, i.e., that they arise from changes in staffing levels rather than from turnover at a fixed level of employment. The former implicitly assumes that change is costly because of disruptions to production as output changes. The latter implies that costs arise more from the inexperience of new workers and from congestion and fixed costs in the personnel office. No empirical study of factor dynamics tries to distinguish between these costs empirically, and no theoretical study examines their different implications. I follow in that tradition here.

2. This assumption merely simplifies the analysis without qualitatively changing the results. With the short time series used in the empirical work a model that allowed for asymmetric adjustment could not be usefully estimated.

3. Rothschild (1971), Davidson and Harris (1981) and Nickell (1986) discuss the solutions to different models that go beyond the standard convex variable costs of adjustment.

4. Using ΔY^{*}_{t+6} instead of ΔY^{*}_{t+3} did not qualitatively affect the results.

5. Trivedi (1983) demonstrates the general problem of inferring the underlying structure of smooth paths of adjustment lags from models estimated using aggregate data. Hamermesh (1990) demonstrates the specific problem of drawing any inferences about speeds or costs of adjustment from aggregate data when the underlying costs are nonlinear.