Labor Demand and the Structure of Adjustment Costs

By Daniel S. Hamermesh*

This study examines the costs firms face in adjusting labor demand to exogenous shocks. Evidence on monthly plant-level data shows that adjustment proceeds in jumps: Employment is unchanged in response to small shocks, but moves instantaneously to a new equilibrium if the shocks are large. Results in the large literature that assumes smooth adjustment are due to aggregation of this nonlinear relation. The finding has implications for cyclical changes in productivity, for examining severance pay, layoff, and plant-closing restrictions, and all other policies that affect the cost of adjusting employment.

Most models of factor adjustment assume smooth paths toward a final equilibrium when the fundamental determinants of factor demand are shocked. Most recent econometric work has even assumed that adjustment is characterized by a geometric lag structure. The purposes of this study are to reexamine the theory underlying these assumptions, to discover whether they make sense empirically, and to consider the implications of alternative estimates that allow one to infer the structure of adjustment costs.

This reexamination is necessary for several reasons. Without specifying and estimating equations properly, we cannot know if predictions of the paths of factor demand are affected by specifications that fail to embody the underlying structure of adjustment costs at the plant level. Second, in most European countries, and increasingly in the United States, too, a variety of labor-market policies has been enacted in the past 15 years that could affect the adjustment of labor demand. (See John Gennard, 1985). Without knowing the structure of adjustment costs, we cannot link specific policies to the costs they might impose.

I begin by examining the conventional wisdom about factor adjustment, including issues of aggregation and discussing the nature of the costs associated with hiring and changing employment. I analyze the optimal path of employment under differing costs of adjustment and specify a set of estimating equations. These are studied using data on individual plants and then on longer time-series on highly disaggregated industries. The analysis provides the first tests of competing hypotheses about the structure of the costs of adjusting labor demand, and it does so using the appropriate micro data.

I. The Conventional Wisdom and the Nature of Labor Costs

The standard model of dynamic factor demand specifies a system such as:

$$
\begin{aligned}
(1)\quad & X_{it} = F(X_{1,t-1},\ldots,X_{i,t-m},\ldots,X_{I,t-M},\\
& \qquad Z_{1t},\ldots,Z_{j,t-n},\ldots,Z_{J,t-N}),\\
& i=1,\ldots,I; m=1,\ldots,M;\\
& j=1,\ldots,J; n=1,\ldots,N,
\end{aligned}
$$

where t denotes time, the X_i are inputs, and the Z_j are exogenous variables. In early studies and in recent studies concentrating on how expectations affect the variables in

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Z, $I = M = 1$—a simple geometric lag structure is imposed and the adjustment of demand for the single input of interest is assumed to be independent of the adjustment of demand for other inputs. (Thus Sherwin Rosen, 1968, examines the employment-hours ratio with $I = M = 1$). In the estimation of large macroeconomic models the assumption is that $M = 1$ has become standard (for example, Ray Fair, 1984).[1]

Convex adjustment costs underlie (1). Apparently this assumption originated in Charles Holt et al. (1960). Yet those authors noted, "Whether these costs [of changes of various sizes in employment] actually rise at an increasing or decreasing rate is difficult to determine" (p. 53). They justified convexity (a quadratic) as an approximation to a cost function with linear variable and no fixed costs. None of the subsequent early studies (Robert Eisner and Robert Strotz, 1963; John Gould, 1968) provided much more justification than did Holt et al. More recent work just imposes the assumption (for example, Thomas Sargent, 1978, p. 1016). There is nothing wrong a priori with this; but the exclusion of fixed costs and the insistence on increasing average variable adjustment costs are restrictive and not necessarily consonant with reality.

In the literature on labor demand only Stephen Nickell (1986, and some of his earlier work) recognizes that changes in employment may be characterized by average variable costs of adjustment that initially decrease but eventually increase. He derives the firm's dynamic demand for labor under both the standard assumption of increasing variable costs and the assumption of constant costs. No existing empirical work on labor demand goes beyond the conventional assumptions.[2]

P. K. Trivedi (1985) shows that there are severe difficulties in drawing inferences about microeconomic adjustment paths from aggregated data. This suggests that empirical work on the adjustment of labor demand should first examine microeconomic adjustment paths to infer the nature of those costs. It should then consider how these paths are aggregated to produce the more readily observable macro paths.[3]

As a first step in this direction, one should note that the cost of hiring facing the firm may be independent of the number of workers hired. Advertising, interviewing, and doing the paperwork to hire one assistant professor of economics is no more costly than that required to hire three. Taking experienced workers away from production to train one worker may be as costly as taking them away to train five workers. Some costs arise only if hiring is done and do not vary with its rate. Beyond the costs of gross employment changes, there are costs of making net changes. Does reducing employment by eliminating a shift reduce profits proportionately more or less than the layoff of a few workers? Do morale problems arise among remaining workers when staffing is cut regardless of the size of the reduction? The structure of the costs of adjusting employment levels need not be convex and may affect the path of employment just as much as the more visible costs of gross employment changes.

[1] Other studies have examined (1) with $I > 1$ under varying degrees of generality about the lags of the inputs and about the Z_j. Thus Daniel Hamermesh (1969) examined gross employment changes; Frank Brechling (1975) and Matthew Shapiro (1986) studied the joint adjustment of employment and capital; and Robert Topel (1982) specified joint adjustment of inventories and employment. M. I. Nadiri and Rosen (1969) included all of these variables.

[2] There has been some discussion of more general adjustment processes of other inputs. Michael Rothschild (1971) studied the adjustment of capital; Alan Blinder (1981) and Andrew Caplin (1985) examined (S, s) models of inventories, essentially assuming both fixed and increasing variable costs of adjustment. Aside from Stephen Peck (1974), who analyzed investment in (very lumpy purchases of) electricity-generating plants, the few empirical studies based on these models use only aggregated data.

[3] In other areas only the second part of this approach seems important. Most investment goods and consumer durables purchases are inherently lumpy. This means that the major question of interest should be the nature of the aggregation of lumpy purchases that generates paths of the observed aggregates.

II. Estimating Adjustment Paths Under Alternative Cost Structures

A generalized adjustment cost function for a homogeneous labor input is:

$$C(\dot{L}) = b\dot{L}^2 + \begin{bmatrix} k \text{ if } |\dot{L}| > 0 \\ 0 \text{ if } \dot{L} = 0 \end{bmatrix},$$

where the superior dot denotes the rate of change, and b and k are nonnegative parameters.[4] Implicitly this cost structure is on net changes in employment, an approach taken in some but not all of the literature. The firm is assumed to maximize the discounted stream of its concentrated profits $\pi(L)$, with $\pi'' < 0$:

$$(2)\quad Z = \int_0^T \left[\pi(L) - b\dot{L}^2 - k\right] e^{-rt}\, dt + \left(\pi(L_T)e^{-rT}\right)/r,$$

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 is implicit in the function π; the product price is assumed to equal one, and L_T is the value of L that is chosen at the endogenous time T. I assume that $L \geq L_0$ (i.e., w has decreased, causing L to be at least equal to its initial level).[5]

In the standard case $b > 0$ and $k = 0$. The optimal adjustment path between $t = 0$ and T is described by the Euler equation:

$$(3)\quad 2b\ddot{L} - 2br\dot{L} + \pi'(L) = 0.$$

This is the standard solution, with $T \to \infty$; the adjustment path is smooth, and equilibrium labor demand is approached asymptotically. As Gould (1968) has shown, it can yield a simple form of (1):

$$(4)\quad L_t = [1-\gamma]L_t^* + \gamma L_{t-1} + \mu_t,$$

where I have written L and L^* as logarithms of actual and long-run equilibrium labor demand. μ is a random error term appended for use in estimation.

In the case of only fixed adjustment costs, $k > 0$ and $b = 0$. The firm either maintains employment at L_0 forever or sets $T = 0$ and jumps immediately to L^*, the long-run equilibrium value of labor demand, depending on whether:

$$k \gtrless \frac{[\pi(L^*) - \pi(L_0)]}{r}.$$

The firm adjusts if L^* is sufficiently different from its most recent choice of L and if k is relatively small. We can describe its employment demand by:

$$(5a)\quad L_t = L_{t-1} + \mu_{1t}, |L_{t-1} - L_t^*| \leq K,$$

and

$$(5b)\quad L_t = L_t^* + \mu_{2t}, |L_{t-1} - L_t^*| > K.$$

The parameter K is an increasing function of the fixed adjustment costs. It is the percentage deviation of last period's employment from desired employment that is necessary to overcome those fixed adjustment costs. μ_{1t} and μ_{2t} are disturbances, with $E(\mu_{1t}\mu_{2t}) = 0$.

To estimate (5), specify L_t^* as:

$$(6)\quad L_t^* = aX_t + \epsilon_t,$$

where a is a vector of parameters, X is a vector of variables that affect L_t^*, and ϵ_t is a disturbance term. Throughout the discussion I assume:

$$E(\mu_{1t}\epsilon_t) = E(\mu_{2t}\epsilon_t) = 0.$$

[4] I exclude a linear term in $\dot{L}$. Were it included, its only effect on the path would be to change the target; were it alone included, it would not be optimal for the firm to lag adjustment of labor demand.

[5] I ignore the issue of employment-hours substitution and assume here that hours per worker are fixed. (See Robert Hart, 1984). Some of the labor hoarding that is apparent in the empirical results clearly reflects variations in hours per worker, on which data are unfortunately not available.

The firm operates on (5a) if:

$$\epsilon_t \leq K + [L_{t-1} - aX_t]$$
$$\text{and } \epsilon_t \geq -K + [L_{t-1} - aX_t],$$

and on (5b) if:

$$\epsilon_t > K + [L_{t-1} - aX_t]$$
$$\text{or } \epsilon_t < -K + [L_{t-1} - aX_t].$$

It jumps to its new long-run equilibrium (moves along (5b)) if it is sufficiently shocked by changes in X or if forecasting errors overstate $|L_{t-1} - L_t^*|$.

We need to construct a method of estimating the parameters in (5)—the a parameters, K, and the variances $\sigma_{\mu 1}^2$, $\sigma_{\mu 2}^2$, and σ_ϵ^2, and to specify L^*. Equations (5a) and (5b) are essentially a switching regression (see Stephen Goldfeld and Richard Quandt, 1976), with the probability of being on (5a) equal to:

$$1 - p_t = \Phi\left[\frac{K + L_{t-1} - aX_t}{\sigma_\epsilon}\right] - \Phi\left[\frac{-K + L_{t-1} - aX_t}{\sigma_\epsilon}\right],$$

where Φ is the cumulative unit normal distribution function (and I have implicitly assumed that ϵ is normally distributed). p_t is then the probability that the firm jumps to L_t^*. The likelihood function for this model is:

$$(7) \quad \mathscr{L} = \prod_{t=1}^{T} g(\mu_{1t})^{1-p_t} \cdot g(\mu_{2t} + \epsilon_t)^{p_t},$$

where $g(\mu_{1t})$ is the density of μ_{1t} from (5a), and $g(\mu_{2t} + \epsilon_t)$ is the density of the error term in (5b) after substituting for L_t^*. Both errors are assumed to be normally distributed. The logarithm of the likelihood function in (7) is maximized in the empirical work.

A huge literature has arisen on the appropriate specification of L^* (see Hamermesh, 1986). Since the available data limit the possibilities severely, I use two different approaches to represent L_t^* in (4) and (5). The first:

$$(8) \qquad L_t^* = a_0 + a_1 Y_t + a_3 t + \epsilon_t,$$

where the a_i are parameters to be estimated, can be viewed as perfect forecasting under rational expectations.[6] The second, based on a simplified version of Nickell's (1984) approach, estimates a transfer function for Y_t using all information available at time $t-1$. This produces the predictions ${}_{t-1}Y_t^*$ and ${}_{t-1}Y_{t+i}^*$, $i = 1, 2, \ldots$. In this approach L_t^* is approximated as:

$$(9) \qquad L_t^* = a_0 + a_1\, {}_{t-1}Y_t^* + a_2 \Delta Y_{t+i}^* + a_3 t + \epsilon_t,$$

where ΔY_{t+i}^* is the change in the forecasted value Y^* from time t to time $t+i$. This equation embodies labor-saving technical change and expectations about sales.

If behavior is described by (5), and firms' $|L_{t-1} - L_t^*|$ and K differ, at any time t some fraction γ_t of the firms in any aggregate will hold employment constant at L_{t-1} (will behave according to (5a)), while $1-\gamma_t$ will adjust according to (5b). If we observe only aggregate behavior, labor demand could be characterized by an equation that looks just like (4). If one ignores the time-varying nature of the p_t and the problems of aggregating firms' p_t to obtain $1-\gamma_t$, (4) may describe aggregate employment dynamics well even though the underlying behavior is characterized by (5).

The case of b, $k > 0$, is described in the Appendix. Essentially b and k jointly cause the long-run equilibrium value of employment to differ from the static profit-maximizing value. Higher fixed adjustment costs increase this difference but hasten the adjustment from L_0 to equilibrium; greater quadraticity of $C(L)$ also increases the difference,

[6] Factor prices are not available in my main source of data. Also, there is some evidence that they are less important in affecting short-run labor-demand fluctuations than are expectations about output (Richard Freeman, 1977).

but it slows the rate of adjustment. Extensive empirical modeling of this general case is left for subsequent research and the collection of better data.

III. Estimates for Individual Plants

To examine the effects of differing structures of adjustment costs at the proper level of disaggregation I acquired data on seven manufacturing plants of a large U.S. durable-goods producer. Monthly data on output were obtained for December 1977 through May 1987, as were monthly employment levels from January 1983 through May 1987. The employment data are mid-month counts of production workers; the output data measure total units produced in the month.[7]

Before estimating (4) and (5), a detailed preview of the results can be obtained from plots of the logarithms of employment and output in each plant, and of the data aggregated over all seven plants. Each plot in Figure 1 shows the last 52 months of the sample; the origin on the horizontal axis represents the minimum value of logarithm (1 + employment). The first seven plots are striking. There are substantial fluctuations in output; but production-worker employment is essentially constant, except for large changes around the time of the larger changes in output. This is seen especially clearly in the data for Plants 1, 4, and 5, but appears to characterize the other plants too. This inference contrasts sharply with the appearance of the data aggregated over the seven plants, shown in the last plot. There are continuous fluctuations in employment, and these roughly coincide with the fluctuations in output. The first seven plots are inconsistent with smooth fluctuations in employment based on a model of convex variable adjust-

[7]No major strikes occurred in this company during the 53 months covered by the employment data. A few plants were shut down by strikes for less than one week, but this does not seem to have affected production-worker employment or monthly output in the seven plants.

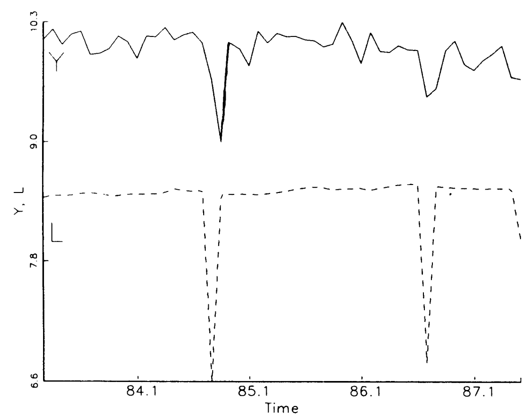

FIGURE 1. PLANT 1

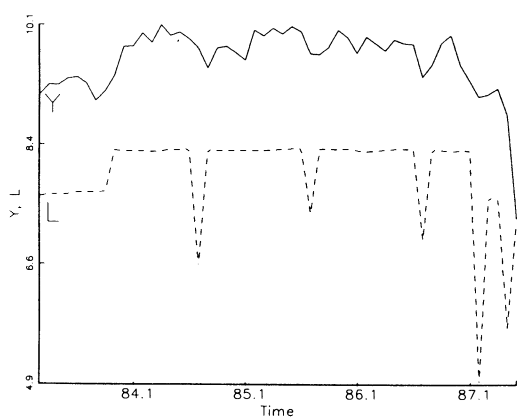

FIGURE 1. PLANT 2

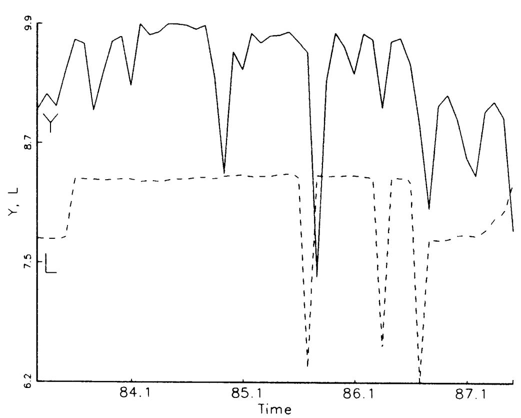

FIGURE 1. PLANT 3

FIGURE 1. LOG (OUTPUT), Y, AND LOG (EMPLOYMENT), L

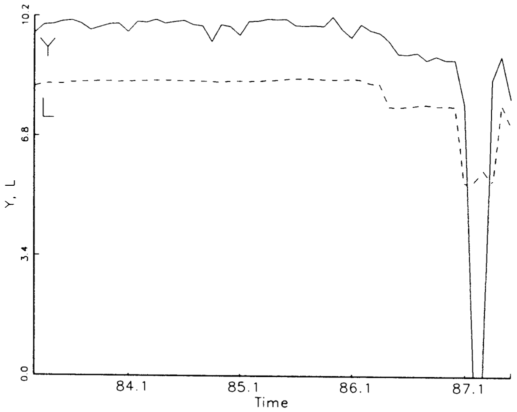

FIGURE 1. PLANT 4

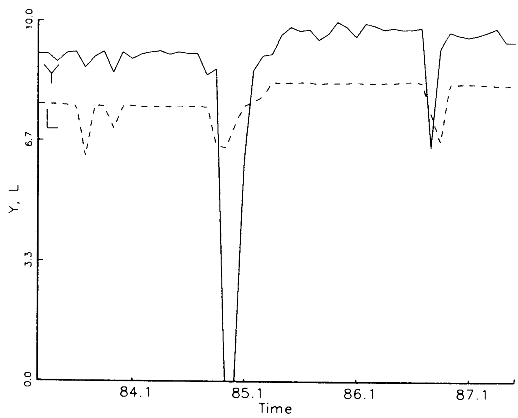

FIGURE 1. PLANT 5

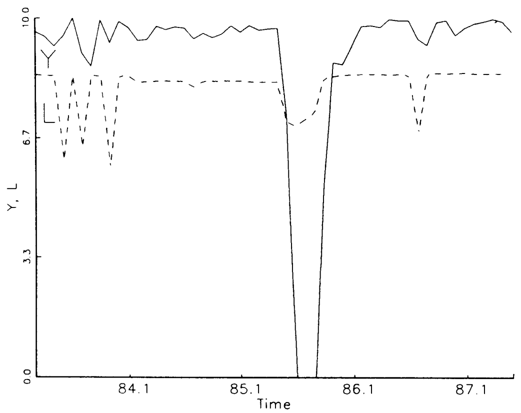

FIGURE 1. PLANT 6

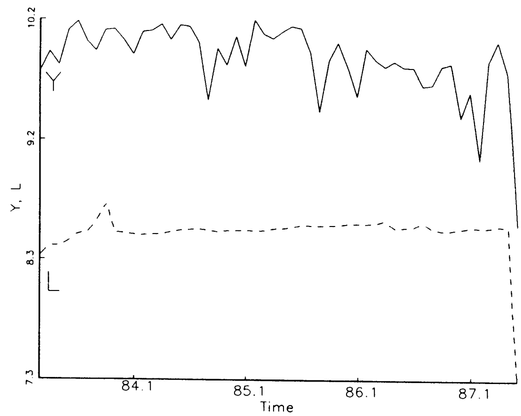

FIGURE 1. PLANT 7

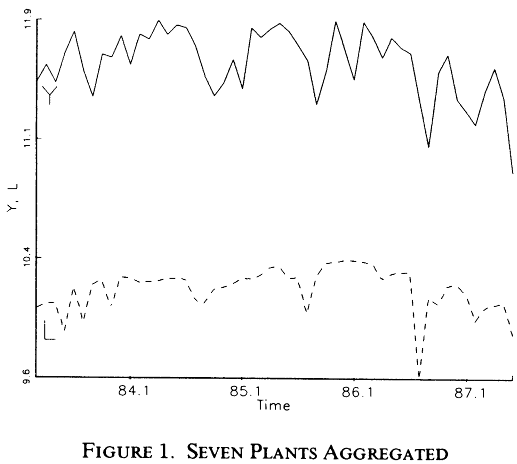

FIGURE 1. SEVEN PLANTS AGGREGATED

ment costs; the last plot appears consistent with that model.

While these figures tell much of the story, they cannot tell us whether the underlying relationship between the logarithms of employment and output is consistent with the static theory of production; nor can they provide insights into the size of the shock, K, that is necessary to induce the firm to change employment in the plant. To make these inferences we must estimate (5) and the accompanying equation, alternatives (8) or (9). Throughout the analysis I use seasonally unadjusted data. Only in Plant 3 was there significant twelfth-order autocorrelation in Y.

To generate the sequences ${}_{t-1}Y_t^*$, I initially used a transfer function based on continuously updated regressions of Y on its 12 lagged values, a time trend, and the 12 lagged values of the company's retail sales. These regressions did fit better than those that excluded the firm's retail sales, but they did not predict Y so well. Accordingly, (4) and (5) are estimated using ARI (12) forecasts of Y. Each forecast is based on the most recent five years of output data.

A comparison of the estimates of (4) and (5) is essentially a test of how the standard model of convex variable costs of adjustment performs relative to a model in which there are fixed adjustment costs (and perhaps variable costs of degree one or less). Under alternative (8) the model in (4) has five parameters, the four regression parameters a_0, a_1, a_3, and γ, and σ_μ. Under the same alternative the switching model has seven parameters, the three a_i, K, σ_ϵ, σ_{μ_1}, and σ_{μ_2}.[8] To make estimation of the system somewhat easier, I assume that $\sigma_{\mu_1} = \sigma_{\mu_2}$. This means that I am restricting the variance of the error in (5a) to be less than that in (5b). This implicitly assumes that errors that occur when the firm seeks to hold employment constant are not so large as those produced when it tries to move from L_{t-1} to L_t^*. The basic switching model thus has six free parameters. We can discriminate between the models in (4) and (5), which are not nested, by examining the values of their likelihood functions.

I begin with a discussion of the estimates of an autoregression of L, and of (9) and two alternatives of (4), which are shown in Table 1.[9] The estimates for the individual plants are not too encouraging, as they contain some negative autoregressive terms in the AR(1) model and in (4), some positive time trends and even a negative coefficient on expected output for Plant 1. This instability across the plants is probably due to the use of microeconomic data and to the short time-series for each plant.

The estimation problems induced by this combination are overcome when either the pooled or the aggregated data underlie the estimation. The results for these two cuts of the data are shown in the first two tableaux of Table 1. In the aggregated data the coefficients on ${}_{t-1}Y_t^*$ are consistent with previous work using industry data; the time trends, particularly in the pooled data, imply that labor productivity grows at about 2 percent per year.[10] The coefficients on the autoregressive term in L, although somewhat lower than those found in most estimates based on monthly industry data, are not unreasonable in the pooled data. More-

[8] Under alternative (9) the number of parameters is one greater for both (4) and (5) because of the inclusion of a_2.

[9] I present results using only the one-month forecast of output and the expected change three months beyond that. Inclusion of a six-month forecasted change did not add to the quality of the fitted equations for any of the plants. Also, because the estimates of (5) for Plant 7 never converged no matter what starting values or algorithms were chosen, results are presented only for six individual plants. The seventh plant is included in the pooled data and in the estimates based on the aggregate of all plants.

[10] We can study the specification errors induced into the equations by the absence of wage data by examining Figure 1 around the one time in the sample period when a substantial amount of wage information became available (when a new collective bargaining contract was negotiated). In only one of the seven plants was there a sharp fluctuation (drop) in employment during that month, and in only one of the other plants did employment fluctuate (drop) during the prior month. It is unlikely that the parameter estimates or inferences about the adjustment paths are greatly affected by the absence of wage data.

TABLE 1—LEAST-SQUARES ESTIMATES, 1983:2–1987:5, MANUFACTURING PLANTS[a]

N.	AR(1)	(9)	(4)		AR(1)	(9)		(4)
	Pooled (7 plants)				Aggregated (7 plants)			
Constant	4.272	6.348	4.479	4.532	6.502	5.874	5.036	5.319
	(11.21)	(29.38)	(11.90)	(12.44)	(4.66)	(4.81)	(3.44)	(4.11)
L_{-1}	0.474		0.312	0.269	0.361		0.164	0.014
	(10.15)		(5.94)	(5.10)	(2.64)		(1.03)	(0.09)
${}_{t-1}Y_t^*$		0.192	0.121			0.372	0.301	
		(8.77)	(5.03)			(3.54)	(2.39)	
ΔY^*_{t+3}		0.042	0.031			0.202	0.194	
		(4.95)	(3.76)			(1.53)	(1.46)	
Y_t				0.151				0.401
				(6.95)				(3.71)
Time		−0.0011	−0.0011	−0.0004		−0.0010	−0.0010	0.0018
		(−0.62)	(−0.61)	(−0.25)		(−0.76)	(−0.81)	(1.42)
$\bar{R}^2$	0.220	0.219	0.287	0.310	0.104	0.149	0.168	0.278
log $\mathcal{L}$			−262.62	−257.11			34.76	37.93
	Plant 1				Plant 2			
Constant	8.966	8.445	8.759	−1.602	6.320	5.305	5.708	0.202
	(7.41)	(4.68)	(4.55)	(−0.73)	(5.67)	(3.05)	(3.18)	(0.12)
L_{-1}	−0.062		−0.077	−0.614	0.205		−0.136	−0.340
	(−0.43)		(−0.49)	(−3.98)	(1.47)		(−0.94)	(−2.15)
${}_{t-1}Y_t^*$		−0.007	0.023			0.344	0.424	
		(−0.04)	(0.14)			(1.84)	(2.06)	
ΔY^*_{t+3}		−0.130	−0.144			0.593	0.616	
		(0.88)	(−0.95)			(1.98)	(2.05)	
Y_t				1.509				1.105
				(5.38)				(4.89)
Time		0.0027	0.0027	0.0069		−0.0236	−0.0267	−0.0048
		(0.57)	(0.56)	(2.25)		(−3.62)	(−3.64)	(−0.95)
$\bar{R}^2$	−0.016	−0.042	−0.059	0.339	0.022	0.273	0.271	0.336
log $\mathcal{L}$			−20.60	13.04			−41.62	−39.72
	Plant 3				Plant 4			
Constant	6.870	7.187	6.823	6.524	1.355	6.537	4.187	3.556
	(6.10)	(6.13)	(4.69)	(4.86)	(2.04)	(13.85)	(3.67)	(4.07)
L_{-1}	0.150		0.065	−0.052	0.828		0.358	0.427
	(1.08)		(0.43)	(−0.30)	(10.01)		(2.24)	(3.27)
${}_{t-1}Y_t^*$		0.130	0.111			0.204	0.135	
		(1.01)	(0.81)			(4.57)	(2.54)	
ΔY^*_{t+3}		0.127	2.16			0.044	0.022	
		(0.90)	(−0.88)			(3.12)	(1.32)	
Y_t				0.226				0.139
				(1.47)				(2.97)
Time		−0.0128	−0.0121	−0.0051		−0.0150	−0.0112	−0.0106
		(−2.03)	(−1.84)	(−1.06)		(−3.24)	(−2.35)	(−2.27)
$\bar{R}^2$	0.003	0.032	0.015	0.056	0.661	0.693	0.717	0.727
log $\mathcal{L}$			−34.42	−33.82			−25.38	−24.95
	Plant 5				Plant 6			
Constant	2.876	6.142	4.005	4.804	7.782	6.708	8.285	8.611
	(3.32)	(14.99)	(4.21)	(5.15)	(6.76)	(16.23)	(8.04)	(8.57)
L_{-1}	0.635		0.360	0.237	0.041		−0.241	−0.266
	(5.76)		(2.46)	(1.63)	(0.29)		(−1.67)	(−1.91)
${}_{t-1}Y_t^*$		0.133	0.076			0.115	0.149	
		(3.10)	(1.61)			(2.88)	(3.37)	
ΔY^*_{t+3}		0.0003	(0.0061)			0.024	0.026	
		(0.01)	(0.29)			(1.67)	(1.82)	
Y_t				0.096				0.142
				(2.77)				(3.86)
Time		0.0196	0.0130	0.0128		0.0133	0.0164	0.0149
		(4.94)	(2.79)	(3.03)		(2.48)	(2.93)	(2.80)
$\bar{R}^2$	0.387	0.388	0.446	0.507	−0.018	0.174	0.203	0.250
log $\mathcal{L}$			−23.79	−21.28			−41.87	−40.79

[a]Here and in Table 2 there are 52 observations in each case, except in the pooled equations, for which there are 364 observations. t-statistics in parentheses here and in Tables 2, 4, and 5 unless otherwise noted.

TABLE 2—ESTIMATES OF (5a)–(5b), 1983:2–1987:5, MANUFACTURING PLANTS

	$\hat{a}_0$	$\hat{a}_1$	$\hat{a}_2$	$\hat{a}_3$	$\hat{K}$	$\hat{\sigma}_\mu$	$\hat{\sigma}_\varepsilon$	$\log \mathscr{L}$	$\hat{p}_t$ (Mean, Standard Deviation) (Minimum, Maximum)
Pooled									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	6.512	0.160	0.046	−0.0004	0.584	0.493	0.159	−230.77	(0.200 0.179)
	(40.80)	(9.24)	(4.00)	(−0.38)	(8.15)				(0.045 0.999)
Y_t	5.985	0.217		−0.001	0.573	0.494	0.621	−234.86	(0.465 0.089)
	(17.91)	(6.19)		(−0.34)	(3.52)				(0.399 0.894)
Aggregated									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	5.132	0.436	0.213	−0.001	0.019	0.128	0.020	38.75	(0.817 0.240)
	(3.42)	(3.34)	(1.71)	(−0.71)	(0.75)				(0.342 0.999)
Y_t	5.488	0.399		0.002	0.031	0.119	0.039	44.09	(0.750 0.210)
	(4.56)	(3.84)		(2.09)	(0.89)				(0.438 0.999)
Plant 1									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	8.521	−0.075	−0.723	0.018	0.792	0.000	0.781	−17.85	(0.395 0.115)
	(2.35)	(−0.18)	(−1.92)	(0.96)	(1.80)				(0.311 0.814)
Y_t	−3.406	1.170		0.004	0.384	0	0.225	25.20	(0.236 0.232)
	(−17.19)	(57.13)		(2.33)	(2.09)				(0.104 0.999)
Plant 2									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	6.255	0.246	0.760	−0.027	0.355	0.512	0.412	−34.69	(0.577 0.186)
	(3.88)	(1.43)	(2.56)	(−5.24)	(2.57)				(0.405 0.999)
Y_t	0.100	0.823		−0.001	0.086	0.555	0.107	−32.77	(0.696 0.221)
	(0.13)	(10.49)		(−0.34)	(2.67)				(0.423 0.999)
Plant 3									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	7.673	0.086	0.139	−0.016	0.113	0.468	0.112	−26.47	(0.739 0.248)
	(5.92)	(0.56)	(0.94)	(−2.21)	(0.85)				(0.311 0.999)
Y_t	6.482	0.188		−0.008	0.131	0.459	0.145	−25.69	(0.724 0.227)
	(27.54)	(7.31)		(−2.20)	(2.34)				(0.377 0.999)
Plant 4									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	4.626	0.453	−0.069	−0.050	1.492	0.000	0.649	27.69	(0.154 0.177)
	(9.93)	(9.65)	(−8.32)	(−16.63)	(12.90)				(0.021 0.995)
Y_t	5.005	0.378		−0.029	1.040	0.000	0.474	34.54	(0.173 0.224)
	(14.70)	(11.83)		(−13.41)	(14.54)				(0.028 0.968)
Plant 5									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	6.694	0.054	0.0179	0.025	0.957	0.063	0.968	−19.69	(0.363 0.080)
	(12.44)	(1.02)	(0.50)	(3.47)	(9.44)				(0.323 0.774)
Y_t	6.270	0.110		0.022	0.523	0	0.672	−16.51	(0.482 0.094)
	(19.01)	(3.25)		(5.66)	(2.10)				(0.436 0.954)
Plant 6									
$_{t-1}Y_t^*, \Delta Y_{t+3}^*$	6.671	0.123	0.027	0.012	0.138	0.578	0.137	−35.44	(0.681 0.238)
	(39.21)	(7.57)	(2.91)	(3.54)	(2.15)				(0.314 0.999)
Y_t	6.651	0.127		0.014	0.131	0.579	0.128	−34.49	(0.591 0.272)
	(19.90)	(5.27)		(2.98)	(1.78)				(0.310 0.999)

over, while perfect forecasting (implicit in the fourth column in each tableau) gives a better fit, the forward-looking terms ΔY_{t+3}^* do add significantly to the equations.

Table 2 shows the maximum likelihood estimates of the switching model (5) for each of six plants, for the pooled data on seven plants, and for those data aggregated.[11] (That

[11] In all cases the procedure MAXLIK in GAUSS is used to find the maxima of the likelihood functions. The particular algorithm chosen is the Davidon-Fletcher-

$\hat{\sigma}_\mu = 0$ in several plants is consistent with the observation that the firm can hold employment constant when that is optimal). While (4) is not nested in (5), and even standard tests of nonnested hypotheses are not applicable with the highly nonlinear model (5), a comparison of log-likelihood values is striking. For all six plants the values of the log-likelihood of model (5) are higher by at least 2 than they are for the equivalent version of model (4) (which has one less estimated parameter).[12] The clearest comparisons are again on the pooled data. This confirms the impressionistic evidence in Figure 1 that the switching model describes these plant-level data far better than does a model of smooth adjustment.[13]

The estimates of K are quite large, implying that the firm varies employment only in response to very large shocks to expected output. In the pooled data $\hat{K} \simeq 0.6$. Consider what an estimate this large means. Unless demand is very slack in these plants, increases in demand that do occur are met by combinations of greater effort and increased hours per worker. This inference is supported by the knowledge that there are large variations in overtime hours in the industry to which these plants belong. With very large changes in product demand, though, firms respond by non-marginal changes in employment. This is the same sequence of responses that is implicit in standard views of how firms adjust. Also as in standard models of adjustment, the estimated employment-output elasticity implies increasing returns to scale. This approach does not remove this well-known problem with partial adjustment models; however, the standard view that employment is adjusted marginally is inconsistent with these data.

The last column of Table 2 presents statistics associated with $\hat{p}_t$. There is substantial monthly variation in the probability that the firm switches to a new equilibrium. Moreover, for most plants, and in the pooled data, $\hat{p}_t$ ranges over most of the interval $(0,1)$. This implies that the model can discriminate fairly well in separating observations onto (5a) and (5b). That the mean of $\hat{p}_t = 0.20$, though, shows that it is usually unlikely that the firm is choosing to change employment.

Recall that these estimates are based on *employment levels*, and thus, like the theory in Section II, implicitly on costs of net adjustment. We do know, though, that voluntary turnover in the four-digit SIC industry to which these plants belong averaged 0.8 percent per month in the late 1970s.[14] If, as seems likely, this fairly large monthly outflow occurs repeatedly in the same jobs, we may conclude that either the variable hiring costs are not very important to this firm or, more likely, that they are not convex and that the fixed costs of hiring are small. The important non-convexity in adjustment costs in these plants is in the level of staffing itself rather than in the activities of the personnel office. The sizes of the estimated K indicate that the lumpiness results from economies of scale in maintaining intact an entire work shift.

I have treated each plant as the locus of decision making; yet the discrete adjustment that has been demonstrated could instead reflect the firm's response to *firmwide* demand shocks. Each plant could be treated as a unit, with the firm reducing output and employment in the least efficient plant when there are shocks to its total demand. This possibility can be examined in two ways. First, in the context of the standard model, add $\bar{Y}_t$ (alternatively, ${}_{t-1}\bar{Y}_t^*$ and $\Delta \bar{Y}_{t+3}^*$), where the superior $(-)$ denotes output among all seven plants, to the versions of (4) estimated in Table 1 for each plant. Among the seven plants the t-statistic on the coeffi-

Powell method. The starting values for the parameters were the OLS estimates of (4), with $K = 0$ and $\sigma_\epsilon = 1$.

[12] I examined first-order autocorrelation in (5) by considering a weighted average of the errors in (5a) and (5b) (with weights $1 - \hat{p}_t$ and $\hat{p}_t$). There was no significant serial correlation in any of the estimates of (5).

[13] As a first approximation to a general model a term in L_{t-1} was added to (5b). It did not significantly raise the likelihood values in the pooled data, and it did so in estimates for only one of the six plants.

[14] No such turnover data are available for the sample period used in estimating (4) and (5).

cient of $\bar{Y}_t$ was significant (at only the 90 percent level) in one plant (Plant 5), and the F-statistics on the vector $({}_{t-1}\bar{Y}_t^*,\ \Delta\bar{Y}_{t+3}^*)$ were also significant only in Plant 5. Firmwide demand shocks add no information to the standard adjustment model at the plant level. Similarly, the contemporaneous correlations of the residuals from these models are low, suggesting there are no common unobserved factors affecting employment adjustment in these plants.

A second approach examines firmwide shocks in the context of the switching model. In particular, if the discrete adjustment is related among the plants, we should find that some plants lead in adjustment while others lag. To examine this, estimate all pairwise vector autoregressions among the $\hat{p}_{it}$, $i=1,\dots 6$.[15] This yields 30 F-statistics testing the hypotheses that $\hat{p}_{jt}$ Granger causes $\hat{p}_{it}$. Of these 30 statistics, one was significantly different from zero at the 95 percent level, and three others were significantly different from zero at the 90 percent level. These results show little relation among the switching probabilities in the six plants. Along with the revised estimates of (4), they suggest that each plant is operated more or less independently of firmwide demand shocks.

It appears that much of the fluctuation in employment in Figure 1 represents temporary decreases that are soon restored to the initial employment level, though this is clearly not always true (for example, in Plants 2 through 5 at various points during the period). This suggests that, while smooth adjustment is not occurring, the discrete adjustment in these plants may reflect employment variation in the presence of contracting behavior. To test this hypothesis against the explanation based on fixed costs of adjustment, consider the model:

$$(10a)\qquad L_t = L^{\max} + \nu_{1t},\quad \text{if } L^{\max} \le a' + Y_t + \nu_{3t};$$

$$(10b)\qquad L_t = a' + Y_t + \nu_{2t} + \nu_{3t},\quad \text{if } L^{\max} > a' + Y_t + \nu_{3t},$$

where the ν_{it} are random-error terms, a' is a parameter, and $L^{\max}$ is the highest value of L_t observed in the plant during the sample period. This model captures the notions in the contracting literature that there is a pool of workers ($L^{\max}$) attached to the plant and that workers in this pool are laid off in bad times in proportion to the size of the shock. (See Martin Feldstein, 1976). I estimate this model and a more general one that allows the firm to use overtime and other variations in hours as a buffer when demand shocks occur. (In the second model I assume the firm can change weekly hours by ± 33 percent in response to demand shocks before laying off workers).

The mean-squared errors from these contracting models estimated on the data covering Plants 1–6 and on the pooled data are shown in columns (2) and (3) of Table 3. Column (1) shows the mean squared errors from the switching model, based on weighted averages of the residuals from the estimation of (5a) and (5b) with $1-\hat{p}_t$ and $\hat{p}_t$ as weights. In Plants 1 and 2 the simple contracting model predicts as well as the switching model, while in Plant 3 the difference is not very large. In Plants 4, 5, and 6, however, the contracting model fails miserably. The reason is straightforward: In those plants output sometimes drops to zero, yet employment does not. The contracting model does not allow for the labor hoarding that takes place even in response to large demand shocks.

No doubt an expanded contracting model that allowed for an employment-output elasticity less than one in the face of large demand shocks would describe the data as well as a model of fixed adjustment costs. Indeed, such contracting can be viewed as one underlying cause of the fixed adjustment costs that produce the behavior observed here. The data are not sufficiently rich to discriminate among alternative explanations for the existence of fixed adjustment costs. They only show that smooth adjustment based on

[15] The VAR models were estimated with four lags of the dependent variable and the current value and four lags of the independent variable.

TABLE 3—MEAN-SQUARED ERRORS, SWITCHING MODEL, AND CONTRACTING MODELS

	Switching	Contracting	
		No Hours Variation	±33 Percent Hours Variation
Pooled (7 Plants)	1.262	3.293	3.271
Plant 1	0.340	0.372	0.330
Plant 2	0.545	0.556	0.542
Plant 3	0.458	0.669	0.661
Plant 4	0.492	1.435	1.427
Plant 5	0.358	1.733	1.729
Plant 6	0.550	2.119	2.193

quadratic variable costs describes behavior poorly.

IV. The Effects of Aggregation

The estimates on the data aggregated over the seven plants present an entirely different picture from those on the pooled data or on the individual plants. The $\hat{K}$ for the aggregated data in Table 2 are insignificant and very small; and the average values of the $\hat{p}_t$ are much higher than in the pooled data. While (5) describes the data better than does (4), the differences in the log-likelihood values are far below the differences in the pooled data, and below most of the differences in the estimates on the individual plants. Even at this very low level of aggregation much of the ability to discriminate between models of adjustment costs is lost.

To examine problems of model discrimination under further aggregation, I obtained monthly data on four 4-digit SIC U.S. manufacturing industries, ones that have had the same definition and have sufficiently long continuous time-series on output and total employment. These are: SIC 2821, plastics materials and resins; SIC 3221, glass containers; SIC 3632, household refrigerators and freezers; SIC 3633, household laundry equipment. Output is monthly also, with the seasonally unadjusted series used here.[16] For both series the data cover 1958–85, except in SIC 2821. Forecasts of Y are constructed exactly as in Section III, and the same models are estimated here. With the loss of the observations needed to produce these forecasts and the desire to begin estimation with a full-year's data, the model is observed over the period 1965–85 (1973–85 for SIC 2821).

Table 4 presents estimates of the same models as did Table 1. In all industries except SIC 3221 the two versions of equation (4) add little explanatory power beyond that provided by a simple AR(1) model. This contrasts sharply with the results in Table 1, where a first-order autoregression generally explained little of the variation in employment. Moreover, except in SIC 3633 the term in ΔY_{t+3}^* is either insignificant or has an unexpected negative sign.

Estimates of (5) under both alternative assumptions about the formation of L^* are shown in Table 5. While the estimates $\hat{a}_i$ make sense, unlike in the previous section the switching model does not uniformly dominate (4): In SIC 2821 the log-likelihood is higher in (4) in one case, and essentially the same in the other. The fluctuations in $|L_{t-1} - L_t^*|$ relative to the $\hat{K}$ are such that

[16]The unpublished output data were provided by Kenneth Armitage of the Board of Governors of the Federal Reserve. Unlike in the plant-level data, there is substantial seasonality in the output data for these industries. (About one-third of the variation in output is accounted for by a bivariate regression of Y_t on Y_{t-12}). Despite this, the estimates presented here are based on seasonally unadjusted data to maintain comparability with the previous section. The inability to discriminate between models of adjustment costs is not affected when the models are reestimated on seasonally adjusted output data.

TABLE 4—LEAST-SQUARES ESTIMATES, 1965: 1–1985: 12, FOUR SMALL INDUSTRIES[a]

	AR(1)	(9)	(4)		AR(1)	(9)	(4)	
	SIC 2821 (Plastics)				SIC 3221 (Glass Containers)			
Constant	0.035	3.382	0.328	0.255	0.794	−0.912	−0.490	−0.760
	(0.61)	(52.06)	(3.96)	(3.13)	(4.96)	(−4.98)	(−2.84)	(−6.57)
L_{-1}	0.992		0.895	0.906	0.812		0.375	0.288
	(76.40)		(44.22)	(46.78)	(21.38)		(7.89)	(9.96)
${}_{t-1}Y_t^*$		0.135	0.032			1.215	0.742	
		(7.86)	(6.32)			(28.63)	(10.42)	
ΔY_{t+3}^*		0.010	0.017			−0.056	−0.165	
		(0.51)	(3.04)			(−2.34)	(−6.47)	
Y_t				0.038				0.892
				(7.44)				(25.16)
Time		−0.0018	−0.0003	−0.0003		−0.0028	−0.0017	−0.0020
		(−15.91)	(−6.74)	(−7.58)		(−31.20)	(−11.05)	(−23.71)
$\bar{R}^2$	0.974	0.742	0.981	0.981	0.645	0.828	0.867	0.902
$\log \mathcal{L}$			539.55	531.74			356.39	398.75
	SIC 3632 (Refrigerators)				SIC 3633 (Laundry Equipment)			
Constant	0.071	2.750	0.520	0.460	0.253	1.670	0.488	0.376
	(1.30)	(16.75)	(3.84)	(3.90)	(3.24)	(15.18)	(4.53)	(3.77)
L_{-1}	0.980		0.800	0.742	0.919		0.738	0.725
	(67.62)		(22.75)	(23.49)	(37.11)		(15.82)	(20.84)
${}_{t-1}Y_t^*$		0.330	0.073			0.368	0.085	
		(9.01)	(3.10)			(14.81)	(2.72)	
ΔY_{t+3}^*		−0.019	−0.023			0.104	0.028	
		(−0.53)	(−1.14)			(5.67)	(2.06)	
Y_t				0.142				0.119
				(8.15)				(7.32)
Time		−0.0038	−0.0008	−0.0010		−0.0016	−0.0005	−0.0005
		(−38.56)	(−5.54)	(−8.05)		(−24.10)	(−4.54)	(−6.94)
$\bar{R}^2$	0.948	0.857	0.954	0.961	0.846	0.712	0.856	0.876
$\log \mathcal{L}$			336.88	359.26			399.15	417.71

[a]Except 1973:1–1985: 12 for SIC 2821, here and Table 5.

TABLE 5—ESTIMATES OF (5A)–(5B), 1965:1–1985:12, FOUR SMALL INDUSTRIES

	$\hat{a}_0$	$\hat{a}_1$	$\hat{a}_2$	$\hat{a}_3$	$\hat{K}$	$\hat{\sigma}_\mu$	$\hat{\sigma}_\varepsilon$	$\log \mathcal{L}$	$\hat{p}_t$
	(Mean, Standard Deviation) (Minimum, Maximum)								
SIC 2821									
${}_{t-1}Y_t^*, \Delta Y_{t+3}^*$	3.870	0.135	0.070	−0.002	0.104	0.008	0.037	535.65	(0.037 0.059)
	(39.59)	(5.94)	(3.01)	(−10.54)	(4.03)				(0.005 0.423)
Y_t	3.305	0.264		−0.002	0.167	0.008	0.069	532.05	(0.025 0.037)
	(10.08)	(3.48)		(−5.48)	(2.57)				(0.006 0.268)
SIC 3221									
${}_{t-1}Y_t^*, \Delta Y_{t+3}^*$	−3.483	1.795	−0.125	−0.004	0.375	0.017	0.164	613.02	(0.059 0.103)
	(−49.07)	(96.07)	(−2.24)	(−28.87)	(9.94)				(0.022 0.999)
Y_t	−1.593	1.383		−0.003	0.611	0.007	0.304	672.99	(0.059 0.083)
	(−2.02)	(7.56)		(−8.61)	(3.06)				(0.045 0.994)
SIC 3632									
${}_{t-1}Y_t^*, \Delta Y_{t+3}^*$	0.441	0.863	−0.669	−0.005	1.926	0.000	1.005	342.24	(0.065 0.013)
	(0.56)	(4.88)	(−2.45)	(−11.79)	(2.24)				(0.022 0.999)
Y_t	2.166	0.461		−0.004	0.376	0.050	0.228	370.93	(0.149 0.076)
	(3.87)	(3.49)		(−9.40)	(2.30)				(0.099 0.569)
SIC 3633									
${}_{t-1}Y_t^*, \Delta Y_{t+3}^*$	2.245	0.238	0.140	−0.001	0.297	0.000	0.224	412.55	(0.209 0.038)
	(8.68)	(4.03)	(3.20)	(−7.99)	(4.93)				(0.184 0.424)
Y_t	1.879	0.320		−0.001	0.237	0.000	0.182	435.93	(0.237 0.067)
	(225.96)	(57.98)		(−9.73)	(55.05)				(0.190 0.628)

the average probabilities of switching to a new equilibrium are very low, and even the ranges are narrow. This too reflects the inability of the data to discriminate between a first-order autoregression and the switching model. At the level of four-digit SIC industries testing competing hypotheses about behavioral differences arising from alternative structures of adjustment costs is confounded by aggregation.

V. Conclusions and Implications

I have demonstrated *on data for a particular set of individual plants* that the standard model of convex variable adjustment costs for labor is inferior to a specification based on fixed costs of adjustment. For an aggregate of plants of one company, and for small U.S. manufacturing industries, one cannot discriminate between the two models. Lumpy employment adjustment in the plants studied here may be atypical of industry generally; but no one has demonstrated smooth adjustment is typical. Smoothness has heretofore only been assumed.

There are several reasons for believing that discrete adjustment of labor demand is important. The first relates to macroeconomic fluctuations in employment and productivity. There is a tradition (Fair, 1969; Robert Gordon, 1979) of including timing effects to capture the observation that productivity grows unusually slowly as the economy nears a cyclical peak. These are imposed in an *ad hoc* fashion; but they are consistent with structures characterized by fixed costs that make linear aggregation impossible. Abandoning the standard model requires expanding models of macroeconomic employment adjustment to include information about the sub-units (in the specification used here, the distribution across (5a) and (5b)).[17]

Slow adjustment has been linked to the imposition of policies that, for example, make it harder for firms to shed labor.[18] It is difficult to see how such policies impose an *increasing* variable cost of adjustment. Unemployment insurance benefits (that are not fully offset by a lower supply price of labor) impose a linear variable cost of adjustment on most employers. Mandatory advance notice of layoffs or plant closings imposes a lump-sum cost that is effective only if the drop in employment exceeds some minimum.[19] One must model the costs of these policies carefully and obtain microeconomic data to get satisfactory estimates of their effects.

These conclusions should give pause to researchers who worry about complex structures of error terms characterizing dynamic factor adjustment under the maintained assumption that adjustment is slow because of increasing variable costs. More attention needs to be paid to linking maximizing behavior to the underlying structure of adjustment costs. That linkage must be made at the micro level, with implications for macro behavior deduced by determining the correct mechanism for aggregation. The estimates here show that the most profitable approach to studying factor, and particularly employment adjustment requires microeconomic data to discover what firms actually do.

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[17]Consider the following example of how this might occur. With fixed adjustment costs, in a simplified model employment change in a plant will be zero if output change $y < K$ and $y > -K$, and be some multiple of y if $|y| \geq K$. Let y be distributed uniformly over the interval $[y^* - a, y^* + a]$, with $\Pr(y = y') = 1/2a$ on this interval and $a > K$. I assume $y^* > 0$, so average output is rising. Then:

$$E(y \mid |y| \geq K) = ay^*/[a - K].$$

A mean-preserving spread in y involves an increase in a, which implies a decrease in $E(y \mid |y| \geq K)$ if $y^* > 0$. For a given aggregate change in output, an increase in the dispersion of output change across sub-units reduces the absolute value of the average output change among those units that are varying employment. Since the average change in employment is a multiple of $E(y \mid |y| \geq K)$, its absolute value is also reduced even though y^* has not changed.

[18]See Nickell, 1979; Simon Burgess, 1988; Hamermesh, 1988, and Katharine Abraham and Susan Houseman, 1987.

[19]The U.S. plant-closing law, P. L. 100-379, provides that employers must give 60 days' advance notice to workers for plant closings and for layoffs expected to last more than six months, if more than 100 workers are involved.

APPENDIX

The general solution to maximizing (2) is characterized by equation (3) and:

$$(A1)\qquad -2b\dot{L}_T + \frac{\pi'(L_T)}{r} = 0,$$

and

$$(A2)\qquad -b\dot{L}_T^2 + \frac{\pi'(L_T)\dot{L}_T}{r} - k = 0.$$

Equation (A2) is a quadratic in $\dot{L}_T$. It has real roots only if:

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

Let $\tilde{L}$ be the static optimizing level of employment. Then $\pi'(\tilde{L}) = 0$, and $L_T < \tilde{L}$ (since we assumed w decreased). Rewriting and substituting in (A1):

$$(A1')\qquad \dot{L}_T \geq \left[\frac{k}{b}\right]^{0.5},$$

and

$$(A2')\qquad \pi'(L_T) \geq 2r[bk]^{0.5}.$$

Equation (A1′) shows that an increase in k raises the rate of adjustment at the terminal point; equation (A2′) shows that as k increases the slope of the profit function at the terminal point increases. An increase in b also increases this slope, but it reduces the rate of adjustment at T.

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