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Adjustment Costs in Factor Demand

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Thought suggests, and experience confirms, that such a dogma [that a scientific theory is none the worse if its premises are unrealistic] will be self-indulging, permitting its practitioners to ignore or play down inconvenient departures of their theories from the observable real world.

Paul Samuelson 1992, p. 242

1. *Introduction*

BUSINESSES CHANGE their demand for inputs more slowly than the shocks to input demand warrant. The standard explanation for this slow adjustment is that, because the firm must incur *adjustment costs* that are inherent in the act of changing the amount of the input used, the response to shocks will not be instantaneous. This slowness need not result from imperfect expectations or short-run supply inelasticity in factor markets: Even if it did not face such problems, the firm might still not immediately alter its use of inputs in response to shocks.

Whether adjustment costs are responsible for firms' slow changes in input demands and what those costs look like should concern economists of many stripes. Microeconomists should be interested in these issues for various reasons, many having to do with their ability to predict the impact of factor-market policies. Many proposals to subsidize or tax the use of an input will affect not merely the eventual demand for the input, but also firms' responses to shocks to input demand. External shocks to factor markets, e.g., the oil shock of the 1970s, will have differing short-run impacts on individual firms depending on how rapidly those firms can optimally adjust their input demands.

To be able to predict the effects of proposed policies or the likely impact of external shocks microeconomists need to know: 1) What is the *source* of the adjustment cost $C_i(\Delta x_i)$ facing the i'th firm, where Δx_i represents the changes in some vector of inputs? At the most basic level, is it costs associated with changing factor demand that generate slow adjustment, or does stickiness arise from other aspects of a firm's behavior or market environment? 2) What are the *structures* of these costs, that is, how does C_i move with variations in the components of Δx_i? Without knowing these structures we cannot predict the path of the firm's demand for x_i in response to shocks. 3) If knowledge of the entire function C_i is difficult to obtain, what is the *size* of these costs at the averages of Δx_i? This information is useful on its own, because higher costs associated with changing the demand for an input reduce the firm's long run demand for x_i.

These issues should also be important to macroeconomists. The aggregate inputs of employment (E) and of worker-hours ($L = EH$, where H is hours of work per time-period) feed into macroeconomists' central focus on aggregate unemployment but are based on firms' changing demands for labor inputs. Aggregate gross investment (I) sums firms' gross changes in their inputs of the services of capital (K) and thus measures responses that are determined by the source, structure, and size of the C_i. Paths of GDP are therefore partly determined by adjustment costs, as are average labor productivity (Y/L) and total factor productivity.

The nature of the relation between the C_i's and the central macroeconomic outcomes is crucial. Do the sources and structures of the C_i's allow us to treat the paths of inputs at the aggregate level as if they are generated by the behavior of a representative firm? Might there be only a few representative C_i's, so that aggregation is straightforward? If the answers to these questions are negative, how does our ability to predict macro outcomes suffer by assuming positive answers?

Much public debate involves applying econometric results to predict the impacts of altering economic policies. Most of the discussion is about long-term responses and is based on estimates of long-run elasticities. Knowledge of structures of adjustment costs is essential for predicting the possibly long and complex path of responses of factor demand to shocks. Because the sources and sizes of adjustment costs affect demands for inputs, knowledge of them should be an important input into debates over the long-run effects of such policies relating to factor demand as mandated severance pay for workers; accelerated depreciation on investment in equipment; enterprise zones; and many others.

This essay has several goals. In Section 3 we illustrate the impacts of making various assumptions about the structure of the C_i and infer what these imply about aggregation and the possibility of inferring the underlying C_i from aggregate data. Sections 4 and 5 discuss the issues involved in inferring the nature of adjustment costs. The analysis includes a review of a burgeoning empirical literature, much based on microeconomic data, that contains some striking findings that, we believe, should alter the way economists think about factor adjustment. All this evidence generates this survey's basic contribution, an evaluation of what, if anything, we know about the central aspects of adjustment costs—their source (and whether in fact firms' dynamic behavior stems from such costs at all), their structure, and their size. That knowledge then permits us in Section 6 to evaluate how adjustment costs should be treated in macroeconomic analysis. It enables us to see where this research should head over the next decade if it is to do more than merely reproduce past work using ever more sophisticated tools. Before beginning to illustrate the issues and draw conclusions, however, it is worthwhile discussing what exactly the components of C_i might be.

2. *What Are Costs of Adjustment, and Why Not Just Record Them?*

A useful way to think about these costs starts with the identity linking changes in the amount of the input to its flows into and out of the firm:

$$\Delta X_t \equiv X_t - X_{t-1} \equiv XI_t - XO_t, \qquad (2.1)$$

where X is some component of the vector x. XI is the inflow and XO the outflow into the stock X, both defined over some time interval t, and by assumption we are dealing with one, perhaps typical firm. For example, XI could be gross investment or hires, and XO might be depreciation of capital or separations of workers. For expositional purposes we deal with only one component of x; generalizing to the entire vector is straightforward. Define the cost of adjustment functions:

$$C^N(\Delta X); \qquad (2.2a)$$

and

$$C^G(XI, XO), \qquad (2.2b)$$

which we call *net costs* and *gross costs* of adjustment.

From (2.1) it is clear that we cannot depict the adjustment costs facing the firm by adding C^N and C^G. Rather, they represent two different ways that these costs have been treated in the literature (with remarkably little recognition by those using one approach of the utility or even the existence of the other). The nature of these functions—their sources, structures, sizes, and the extent of their heterogeneity across firms—underlies the debate about adjustment costs and determines those costs' importance. There is no reason for gross and net costs to be similar along any of these four dimensions.

For workers (treated for now as an input that is homogeneous once it has been trained and whose hours are fixed) the net costs are those of changing the numbers of employees in the firm. These costs include disruptions to production occurring when changing employment causes workers' assignments to be rearranged (implicitly assuming no change in the capital stock) and all other costs that are not related to the identity of the workers but instead depend solely on changing the number of employees, E (or L if we deal with worker-hours).

Gross costs of adjusting labor demand are those related to the flows of workers, i.e., to changing the identity of the individuals filling a fixed number of jobs. They include among others: Search costs (advertising, screening, and processing new employees); the cost of training (including disruptions to production as previously trained workers' time is devoted to on-the-job instruction of new workers); severance pay (mandated and otherwise); and the overhead cost of maintaining that part of the personnel function dealing with recruitment and worker outflows. All of these can be substantial even if $\Delta X = 0$, as new workers must be hired and trained to replace those who depart (whose possibly involuntary departure also generates costs).

The firm's optimal net investment can be positive ($\Delta X > 0$), zero ($\Delta X = 0$) or negative ($\Delta X < 0$). Changes in the capital stock are linked by (2.1) to gross investment and depreciation. More broadly considered, bankruptcy of firms and the closing of plants by a multiplant firm would also be included under the rubric of net investment. While the cost of net adjustments in the stock of capital underlay some early theory (Robert Lucas 1967), the notion of gross adjustment costs has received most of the attention and much more than it has in the analysis of the demand for labor, presumably because of the difficulty of valuing capital and the relative lack of satisfactory data.

Changing the level of capital services (either the capital stock or its rate of utilization) generates net adjustment costs as an unchanged workforce's routine is disrupted and tasks are reassigned and restructured. Gross costs arise when the delivery of newly purchased equipment and structures takes time. This constrains production, as installing newly purchased equipment or structures shifts other inputs away from current production; as workers' learning-by-doing with the newly installed equipment takes time and reduces output; and as scrappage (XO) produces disruptions when workers must be reassigned to the remaining equipment and structures. The irreversibility of many investment projects, caused by the lack of a secondary market for many capital goods, means that uncertainty about future shocks makes firms hesitant to purchase new capital, thus creating substantial costs of adjustment attached to changing the stock (Avinash Dixit and Robert Pindyck 1994).

All of these costs might arise naturally out of the environments the firm faces in its factor markets and in the nature of technology it uses. Adjustment costs might also be the result, however, of the direct or indirect effects of government policies. Among the many examples are: 1) Mandatory advanced notice of layoffs, which can result in potentially large and often analytically complex effects on employers' reactions to demand shocks (as outlined initially by Samuel Bentolila and Giuseppe Bertola 1990); 2) Variations in the structure of financing mandated unemployment compensation, which might alter the way that employers hire and fire (because of the effects on gross adjustment costs); 3) Changes in the extent of subsidies to new investment in capital equipment (e.g., accelerated depreciation in tax schedules), which can induce changes in the paths of firms' optimal capital stock.

The continuing costs of labor services—payroll and benefit costs—are easy to measure and are reported (in the case of payroll) on a regular basis. Companies' annual reports provide information on capital spending (I). Ascertaining the structure of adjustment costs may require econometric information; but one wonders why it should not be easy to obtain information on the sources and sizes of adjustment costs. The reason is probably that many of these costs are implicit, in that they result in lost output and are thus not measured and reported on an income and expenditure statement generated by the firm's accounts. For example, adding a new machine may result in difficulties in rescheduling the flow of work across other machine sites within an establishment, problems that in turn reduce average efficiency during the period of adjustment. Disruptions may arise when a few new employees join a work crew and senior workers spend time training them. It is very difficult to measure what Arthur Treadway (1971) called these *internal costs* of reduced efficiency during the period of adjustment.

Where the adjustment costs are *external*, in the sense that they do not occur as part of production, there may be more hope of direct measurement. For capital services both gross and net costs are internal, so that we should not expect to generate estimates of the size of adjustment costs through simple accounting methods (and, in fact, none has been generated). For labor the average and total cost of severance payments (such as unemployment benefits); fees to placement agencies; contracted training, and the cost of maintaining the personnel office should be easily measurable.

Despite what might seem like a

straightforward task, surprisingly few estimates have been made even of the external costs of adjusting employment. Beginning with Walter Oi (1962) there have been several careful attempts at inferring the accounting costs of turnover within particular firms and occasional studies of broader groups of employers on some of the costs of hiring and firing. The best survey (Merchants and Manufacturers Association 1980) and some good accounting studies (Peter Button 1990; Wayne Cascio 1991) suggest that direct observation generates the following extremely tentative conclusions: 1) The external costs alone of adjusting labor demand are large, with some of the studies suggesting they amount to as much as one year of payroll cost for the average worker; 2) The average cost of adjustment rises very rapidly with the skill of the worker. Thus while external costs may be very low in jobs filled by high-turnover, low-skilled workers, they are very large for high-skilled jobs that are usually occupied by long-tenure workers; and 3) Costs of hiring exceed costs of separations. Of these three conclusions, only the last should be surprising to the astute observer.

Despite the near impossibility of going beyond measuring just some of the adjustment costs, the relative paucity of estimates is surprising. Economists are unlikely to engage in the type of research that could broaden our knowledge of this part of C^N and C^G; but we would learn a lot if there were more surveys and cost-accounting studies that measured them and encouraged business-owners to record them more systematically than they now do.

3. *Factor Adjustment Under Different Structures of Costs*

A large variety of issues is important in considering the dynamics of the demand for inputs. For example, what is the time period over which the operator Δ is defined? Can we be sure that the adjustment that we observe stems from the costs associated with adjusting factor demand? What are the component(s) of x? These issues relate to measurement and to the question of what the ultimate sources of slow factor adjustment are. We return to them in the two subsequent sections.

We concentrate in this section on the size and structure of the cost of adjusting factor demand, under the assumption that the only possible reason for slow adjustment (once expectations about shocks are accounted for) is the explicit costs associated with altering the demand for the particular factor. This issue has received by far the most attention in both the theoretical and empirical literatures. We examine the path of demand for a single input X, whose cost of adjustment we denote for the typical firm by $C(\Delta X)$. Aside from its expositional simplicity, concentrating on one input has the advantage of making clear the concern of most of the empirical literature.

A remarkable variety of forms have been proposed for $C(\Delta X)$ (see Russell Davidson and Richard Harris, 1981, for a partial catalog). Here we discuss four structures for this function that have figured in the literature, in each case going through the implications of the particular functional form for the path of adjustment of demand for X and for aggregating demand across firms. After discussing them in Subsections A-D, in Subsection E we present a graphical comparison that distinguishes their implications for the path of factor dynamics. We devote roughly similar amounts of attention to each of these forms, despite the predominance of the first in empirical and theoretical work.

A. *Symmetric Convex (Quadratic) Costs*

The literatures on both labor and investment demand have overwhelmingly relied on one form of $C(\Delta X)$, that of symmetric convex adjustment costs, and have restricted the particular form to be quadratic:

$$C(\Delta X) = .5b[\Delta X]^1, b > 0.^1 \qquad (3.1)$$

Here and in the rest of Section 3 we assume that the form of C (though obviously not its argument) is unchanged over time. That simplifying assumption is necessary for the derivations here, though it has been abandoned and other, very restrictive conditions imposed by a few authors (beginning with Peter Tinsley 1971). Also note that we are initially ignoring the distinction between gross and net costs by assuming turnover (depreciation) is zero. At various points in this section we examine how abandoning this assumption affects the inferences.

Form (3.1) imposes a particular convexity on $C'(\Delta X)$, with $C'(0) = 0$. This convexity means that the marginal cost of varying X is increasing in ΔX. Continuous differentiability around $\Delta X = 0$ and the minimum at that point guarantee that changes in market conditions, however small, will cause the firm to alter X continually. Form (3.1) also imposes symmetry around $\Delta X = 0$, so that the (increasing) marginal cost of raising X is equal to that of a similar-size cut in X.

The genesis of the use of this function in studying adjustment costs provides fascinating testimony to the validity of the epigraph to this essay. In their pioneering study based on direct observation of input decisions by a paint manufacturer, Charles Holt et al. (1960) characterized the net costs of changing employment by Figure 1 (a reproduction of their Figure 2–2).[2] The authors believed that "the quadratic curve . . . is a suitable first approximation," but noted that, "It is not required that these costs be symmetrical" (Holt et al. 1960, pp. 52–53). That this was an approximation and that symmetry need not be imposed were quickly forgotten in the published literature, no doubt because of the analytical tractability of (3.1). Researchers ignored the solid line and implicitly centered the dotted approximation on the vertical axis. The specification in (3.1) quickly came to underlie theoretical work on dynamic factor demand (Robert Eisner and Robert Strotz 1963; John Gould 1968) and to rationalize using simple smooth lag structures in empirical studies. Except for an occasional rare complaint about its lack of generality, equation (3.1) underlay essentially all re-

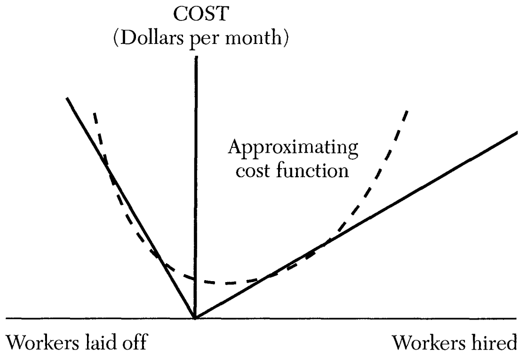

Figure 1. Approximation to Adjustment Cost

Source: Holt et al. (1960, Fig. 2–2. Hiring and layoff costs. Monthly changes in the size of the work force, $W_t - W_{t-1}$).

[1] Some studies have also included a linear term in $|\Delta X|$ in (3.1). Because its inclusion does not alter the essence of the problem, we use the simpler form with the quadratic term only.

[2] They equated positive net changes with hiring, and negative net changes with layoffs, implicitly assuming that no voluntary separations would occur.

search on the dynamics of factor demand until the late 1980s.

Consider what (3.1) implies about the path of adjustment. We assume that there is no natural loss in the stock of X (no depreciation of capital nor quits by employees). For purposes of exposition we thus assume that $C^N(\Delta X) \equiv C^G(XI,XO)$.[3] Let the firm maximize the expected present value V_t of its stream of future profits π:

$$V_t = E_t\{\Sigma_{i=1}^{\infty}[1+\rho_{t+i}]^{-i}\pi_{t+i}\} \qquad (3.2)$$

There is a vector of forcing variables that shocks the demand for X, which we denote by Y and assume is exogenous. We assume decision makers in the firm are risk-neutral and have rational expectations, $E_t\{\bullet\} = E_t\{\bullet \mid \Omega_t\}$, based upon the information Ω_t available at time t about the paths of shocks. Maximization of the firm's value is equivalent to minimizing the present value of its expected stream of costs under the accounting identity:

$$\Delta X_{t+i} = X_{t+i} - X_{t+i-1} \qquad (3.3)$$

This minimization yields:

$$E_t\Sigma_{i=0}^{\infty} c_{t+i} = E_t\{\Sigma_{i=0}^{\infty}[.5[aY_{t+i} - X_{t+i}]^2 + .5b\,[\Delta X_{t+i}]^2][1+\rho_{t+i}]^{-i}\}, \qquad (3.4)$$

where a is a vector of parameters relating the variables in Y to the optimal path of X generated by the static model without adjustment costs ($b \equiv 0$).

This specification has become standard in the macro literature (as in Olivier Blanchard and Stanley Fischer, 1989, from which this part of the discussion is adapted). It makes an extremely simple assumption about the nature of the profit function, namely that departures from peak profits are quadratic *both* in adjustment costs and in deviations of the actual demand for X from the optimal path aY. This allows us to obtain specific solutions to the firm's maximization problem. Note too that it implies that the firm is a price-taker in all markets in which it operates. Letting it set product or factor prices leads to substantial complications.

Under fairly simple assumptions about the process generating shocks to Y_t (for example, a first-order autoregressive process) and a constant ρ, as in Thomas Sargent (1978), optimal forecasting implies replacing E_tY_{t+i} with Y_t, Y_{t-1}, etc. This makes the estimating version (3.5) exactly like the basic models of Leendert Koyck (1954) that were estimated for 25 years before any theoretical rationalization for them was proposed:

$$X_t - X_{t-1} = [1-\lambda][X_t^* - X_{t-1}], \qquad (3.5)$$

where X_t^* is the set of variables that represents the vector of expectations about the long-run demand for X. The parameter λ is a nonlinear function of a, b, and ρ, with $|\lambda| < 1$.[4] If all the assumptions in the derivation hold, the closer the estimated lambda is to one, the larger are the implied adjustment costs and the slower is the rate of adjustment of X_t.

The importance of the "suitable first approximation" and the imposition of symmetry in (3.1) cannot be underestimated. These do more than provide a basis for the estimating equation (3.5). Under the assumption that all firms face the same (3.1), (3.2), and (3.4), even if they face different shocks, the linearity of (3.5) allows its aggregation. Thus under these assumptions (3.5) can be applied to aggregated data with no additional consideration while retaining its theoretical basis. This allows the analyst to infer λ

[3] This assumption is consistent with most of the literature on the demand for labor. The literature on investment demand generally assumes a constant rate of depreciation of the capital stock, with the appropriate modifications in the following.

[4] Larry Epstein and Michael Denny (1983) show in a multifactor context the overidentifying restrictions on the parameters of this reduced form.

(and thus the relative size of the adjustment costs) from readily available aggregate data without having to search for microeconomic data or to worry about problems of aggregation.

The formulation (3.5) has mutatis mutandis become standard in forecasting models and in the simulation of general equilibrium macro, growth, and tax-policy models (Ray Fair 1994; Robert King and Sergio Rebelo 1993; and Lawrence Goulder and Lawrence Summers 1989, among many). Its validity for these purposes depends on how much is lost in our ability to track fluctuations in factor demand when the approximation in (3.1) is imposed. The intellectual validity of the approximation is essentially an empirical issue that can be discovered only by testing it against other specifications of $C(\Delta X)$ using appropriate data. Simply imposing (3.1), no matter how many times it has been done, in no way speaks to the correctness of the underlying assumption.

B. *Asymmetric Convex Costs*

There is no necessary reason why the marginal cost of increasing X would be the same as that of an equal-size decrease. For example, at the macro level positive adjustments in input utilization differ substantially in magnitude and duration from downward ones. If positive changes are more costly, not only will it take longer for X to rise from a trough to a peak, but the troughs will be deeper.

Consider one particularly convenient form of convex adjustment costs that allows for asymmetry in marginal costs and contains (3.1) as a special case (Pfann and Bart Verspagen 1989):

$$C(\Delta X) = .5b[\Delta X]^2 - c\Delta X + \exp(c\Delta X) - 1, \quad (3.6)$$

where b and c are parameters. Adjustment costs represented by form (3.6) are zero if $\Delta X = 0$. They are symmetric only if $c = 0$, in which case (3.6) reduces to (3.1). If $c > 0$, the marginal cost of a positive adjustment exceeds that of a negative adjustment, and vice versa if $c < 0$.

Substituting (3.6) into (3.4) gives the firm's cost-minimization problem:

$$E_t\left\{\Sigma_{i=0}^{\infty} c_{t+i}\right\} = E_t\left\{\Sigma_{i=0}^{\infty}[.5[aY_{t+i} - X_{t+i}]^2 + .5b[\Delta X_{t+i}]^2 - 1 - c[\Delta X_{t-i}] + \exp(c\Delta X_{t+i})][1+\rho_{t+i}]^{-i}\right\}. \quad (3.7)$$

Minimizing (3.7) with respect to X_t yields the Euler equation:

$$E_t\{[1 + \rho_{t+1}]^{-1}[b\Delta X_{t+1} + c[\exp(c\Delta X_{t+1})-1]\} - b\Delta X_t - c[\exp(c\Delta X_t)-1] + X_t = aY_t\,. \quad (3.8)$$

With $c = 0$ this is the Euler equation that would yield the closed-form solution that underlies the description of the path of X_t in (3.5). There is, however, no explicit analytical solution for the reduced form in (3.8), and stability conditions must be met for the structural parameters of this nonlinear Euler equation to be estimated.

The target level of X_t is affected by the adjustment costs only insofar as the user costs that they add to total factor cost must be amortized, so that marginal benefits must equal marginal costs. With adjustment costs that are asymmetric with respect to changes in X_t the dynamic path that is implied by the firm's maximization differs from that which is derived under symmetric regimes (as derived by Pfann and Franz Palm 1993). The path cannot then be described explicitly by the simple Koyck-type adjustment mechanism (3.5).

Under certain conditions a representation based on convex asymmetric adjustment costs can be used to infer the path of factor demand from aggregated data. Assume that the available set of data contains information on an aggregate of M firms, $m = 1, \ldots, M$, that face the adjustment cost functions:

$$C_m(\Delta X_{mt}) = .5b_m[\Delta X_{mt}]^2 - c_m[\Delta X_{mt}] + \exp(c_m \Delta X_{mt}) - 1. \quad (3.6')$$

Abstracting from attrition through time—assuming that firms live forever—each firm's (3.6′) can be written as a Taylor-series expansion around $\Delta X_{mt} = 0$. These can then be aggregated to yield an expression that is identical to the Taylor-series expansion around $\Delta X_t = 0$ of (3.6), so that (3.6) might be interpreted as describing the behavior of the representative firm in an aggregate of heterogeneous firms. In the absence of idiosyncratic shocks and with a fixed number of firms asymmetric adjustment costs at the firm level imply aggregate asymmetric costs of adjustment. Aggregate data can thus be used to estimate the structural parameters of (3.6). Although relaxing the assumption that the population of firms is unchanged does not alter this conclusion qualitatively, allowing for idiosyncratic shocks clearly does.

C. *Piecewise Linear Costs*

Piecewise linear adjustment costs, first discussed in detail by Nickell (1978) and recently given substantial attention in the work of Dixit and Pindyck (1994) and others, are one specification that gives rise to a discontinuity in optimal decision rules. (Michael Rothschild, 1971, proposed and analyzed the basic implications of linear adjustment costs.) Lumpy costs, discussed in the next subsection along with the aggregation problems that are similar in both cases, are another. We assume costs are proportional to changes in X:

$$C(\Delta X_t) = \begin{pmatrix} b_1 \Delta X_t, b_1 > 0 \\ b_2 \Delta X_t, b_2 < 0 \end{pmatrix} \begin{matrix} \text{iff } \Delta X_t \geq 0; \\ \text{iff } \Delta X_t < 0, \end{matrix} \quad (3.9)$$

with b_1 not necessarily equal to $-b_2$ to allow for possible asymmetry. That C is positive but linear for all nonzero ΔX is what enables this representation to generate interesting implications. As in the previous two subsections even a tiny change in the level of X induces positive costs; but here the marginal cost of an adjustment is constant except at $\Delta X = 0$ (where it is undefined). Thus it may be optimal for the firm not to change X until the compensating benefits offset the cost of taking action to adjust to the optimal level. The value of waiting to adjust factor demand determines the optimal timing when to take action, while the duration of the inaction is related to the slope of the adjustment cost function. Once the decision to act has been made, the adjustment is instantaneous and reaches the target implied by the profit function, including the need to amortize the costs of adjustment. (The adjustment is immediate if the discount rate $\rho = 0$.)

Using the same representation as in Section 3A, the firm's adjustment path is the solution to the dynamic cost-minimization problem:

$$\min E_t\{\Sigma_{i=0}^{\infty}[0.5\,[aY_{t+i} - X_{t+i}]^2 + \max(0, b_1 \Delta X_{t+i}) + \max(0, b_2 \Delta X_{t+i})]\,[1 + \rho_{t+i}]^{-i}\}. \quad (3.10)$$

The derivative with respect to X_t changes with the sign of ΔX_t. If we assume (following Nickell 1978) that ρ is fixed and Y is nonstochastic, we obtain a switching regime across the pair of Euler equations:

$$aY_t - X_t + b_1 + Z_t = 0\,, \quad \text{iff } \Delta X_t \geq 0; \quad (3.11a)$$

$$aY_t - X_t + b_2 + Z_t = 0\,, \quad \text{iff } \Delta X_t < 0; \quad (3.11b)$$

with

$$Z_t \equiv E_t\left\{[1+\rho]^{-1}\frac{\partial C(\Delta X_{t+1})}{\partial X_t}\right\}$$

Optimal behavior is determined by (3.11) subject to the definition (3.3). If:

$$aY_t - X_t + b_1 + Z_t > 0,$$

the firm increases X_t such that $X_t = aY_t + \rho b_1/[1 + \rho]$. If:

$$aY_t - X_t + b_2 + Z_t < 0,$$

it decreases X_t such that $X_t = aY_t + \rho b_2/[1 + \rho]$. If neither inequality holds, the firm does not alter X_t. Higher absolute values of b_1 and b_2 thus lengthen the periods of inaction in response to shocks. If the shocks follow a cyclical path, this means that factor demand will be sticky longer around the turning points of the cycle. If adjustment costs are specified as in (3.9), the simple difference equation (3.5) cannot be used to describe the adjustment of demand for the input.

D. *Lumpy Costs*

The epigraph to Marshall's *Principles*, *natura non facit saltum* (nature does not make leaps), underlies much of the approach of modern economists, but it does not necessarily describe all economic behavior. *Saltus* may be the natural results of the adjustment costs facing firms in factors markets. The decision to build a new factory, engenders lumpy adjustment costs that are at least partly independent of the size of the factory. The gross, external costs of obtaining plans, of acquiring a site and of creating new networks for selling the plant's output all produce some fixed components. Some of the costs of hiring—advertising, screening, and training, and others—are up to a point independent of the number of hires.[5] Even some internal costs may be lumpy: Productivity may be disrupted when new workers enter the workplace, even if there is no net employment change, with the extent of disruption possibly independent of the size of the flow of hires. Similarly discrete disruptions may be produced when new machinery is put on line. One could include both lumpy and piecewise linear costs along with a quadratic term and describe adjustment in a more complex manner. Indeed, Andrew Abel and Janice Eberly (1994) do exactly this, viewing the linear costs as those of buying or selling uninstalled capital.

One simple representation of adjustment costs that are exclusively lumpy (but possibly asymmetric, as in Section 3C) is:

$$C(\Delta X_t) = k_1 I_1(\Delta X_t) + k_2 I_2(\Delta X_t)\ , \quad (3.12)$$

where the I_j are indicator functions, with $I_1 = 1$ if $\Delta X_t > 0$, and 0 otherwise; and $I_2 = 1$ if $\Delta X_t < 0$, and 0 otherwise. The $k_j > 0$ indicate the sizes of the lumpy costs, and for simplicity we deal only with net costs.[6] Using the same simplifying assumptions about the profit function as earlier in this section, we assume that the profit-maximizing firm seeks to minimize:

$$\begin{aligned} E_t\Sigma_{i=0}^{\infty}\, c_{t+i} = E_t\{\Sigma_{i=0}^{\infty}\,[.5[aY_{t+i} \\ - X_{t+i}]^2 + k_1 I_1(\Delta X_t) \\ + k_2 I_2(\Delta X_t)][1+\rho_{t+i}]^{-i}\} \quad (3.13) \end{aligned}$$

Even with the simplifying assumption about production no general solution for the path of X can be obtained under this type of adjustment cost. An explicit solution is possible if we assume static expec-

[5] A good example of this is hiring assistant professors of economics in North America. Whether one or six are being sought, advertisements are placed in the *Job Openings for Economists*; the clerical costs of handling the deluge of applications and assembling potential hiring pools must be incurred; interviewing suites are reserved at the annual meetings, and teams of interviewers are subsidized to attend.

[6] The symmetric version of this formulation was introduced by Hamermesh (1989).

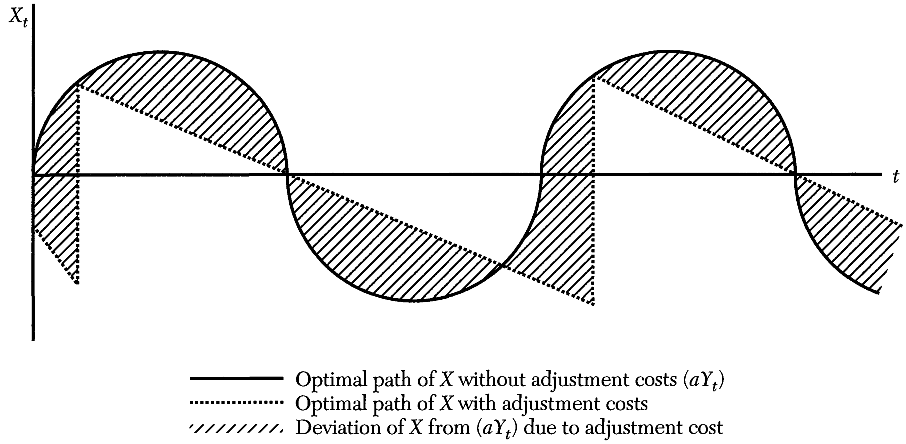

Figure 2. Input Demand Dynamics with Attrition and Lumpy Adjustment Costs

tations on Y and ρ. In that case the firm sets:

$$X_{t+i} = aY_t, i = 0,1,\ldots,\text{if } k_1 \leq \tilde{Z}_t \ \ \tilde{Z}_t \ \ [> 0,$$

$$\text{or } k_2 \leq -\tilde{Z}_t \ \ \tilde{Z}_t \ < 0;] \quad (3.14a)$$

$$X_{t+i} = X_{t-1}, i = 0,1,\ldots,\text{otherwise}, \quad (3.14b)$$

where $\tilde{Z}_t \equiv [1 + \rho_t][aY_t - X_{t-1}]/\rho_t$. The firm jumps to its target demand for X if the present value of the costs of not jumping exceeds the immediate lumpy adjustment costs of making the jump. Larger adjustment costs (larger k_j), a higher discount rate (larger ρ) and a smaller discrepancy between X_{t-1} and aY_t reduce the chance that the firm alters its input of X.

Static expectations make little sense in this or other contexts. Assume instead that the firm has rational expectations, but make the simplifying assumption that the vector Y contains only one forcing variable and that there is a stationary zero-mean process generating Y_t. Under these assumptions one can show that the firm is less likely to alter its input of X the greater are adjustment costs k_j and the smaller is the persistence of shocks. If the firm does alter its demand for X, it will do so discretely to what it believes to be its profit-maximizing level; but the size of the discrete change in X cannot be derived analytically. There is, however, a long literature (of which several of the studies in Kenneth Arrow, Samuel Karlin, and Patrick Suppes, eds. 1959, are antecedents) that derives numerical solutions for such models under assumptions about the structure of stochastic shocks.

Observing smooth adjustment based on data describing industries or higher aggregates over time is uninformative about firms' structures of adjustment costs and in no way disproves the existence of lumpy costs. The simplest way to see that adjustment at the aggregate level depends on second- and higher-order moments of the shocks is to imagine that some fraction of firms adjust each period, while the rest do not. Only by chance will the higher average upward adjustment equal the higher average downward adjustment (Hamermesh 1993b).[7] We discuss the aggregation problem under nonconvex costs in Sec-

[7] The discussion of aggregation under piecewise linear adjustment costs proceeds analogously, except that changes in X are continuous once they occur. Under those costs aggregation prevents us from observing times when X is optimally held constant.

tion 6 and link it directly to using the microeconomic structure of these costs to analyze macroeconomic behavior.

We have not considered attrition—voluntary turnover or depreciation—because it changes none of the results in a basic way. It can be important, however, when we seek to distinguish between aggregable cost functions, such as convex asymmetric costs, and piecewise linear or fixed adjustment costs. Figure 2 shows the dynamic path of the demand for X with a constant attrition rate and lumpy costs. In the example depicted here we assume that the path implied by the forcing variables, aY_t, has no trend around the initial input level X_0. Attrition allows the firm to reduce its factor demand by not replacing inputs that are no longer useful (workers who quit, or depreciated capital) rather than directly reducing the stock of the input (firing workers or selling capital). Introducing attrition can generate an apparent asymmetry into the adjustment path. With a sufficiently high attrition rate, of the amount implied in the example in Figure 2, it takes most of the upswing before it pays the firm to replace and expand X_t, while a cut in X_t is almost fully accomplished by attrition.

E. *A Graphical Comparison of the Structures and their Implications*

Figure 3 summarizes the four structures of adjustment cost discussed in the previous subsections and presents their implications for the path of factor demand. Figure 3a shows the symmetric convex costs implied by (3.1). With such costs the actual path of the input (the dotted line in the right-hand figure) exhibits less variation than would be observed if adjustment costs were zero and input demand followed the path implied by the vector of forcing variables alone, the path aY_t. Figure 3b maintains the assumption of convexity but introduces asymmetry, as in (3.6), with the costs of $\Delta X > 0$ exceeding those of $\Delta X < 0$ in this example. Though the fluctuations in aY_t are of equal amplitude around X_0, the asymmetry of adjustment costs causes X to fall more rapidly than it rises and its path to deviate from that of aY_t by more when the optimal level of the input is above X_0 than when it lies below it. This difference results from the difference in adjustment speeds induced by the asymmetry in $C(\Delta X)$.

Figure 3c illustrates piecewise linear costs of net changes in the input, as in (3.9), in this example with the cost of positive changes exceeding that of negative changes. The asymmetry generates the same greater deviation of actual from long-run input demand when the latter is above trend as in Figure 3b. More important, linear costs in the presence of forward-looking behavior generate periods when X does not vary, even though aY_t is changing. This fixity arises because firms do not wish to incur the adjustment costs of adding to the level of X if they will shortly find it necessary to incur the costs again when aY_t decreases. Because the marginal cost of adjustment is constant (except at zero), there is no extra cost to adjusting X discretely. Finally, Figure 3d illustrates the lumpy (and asymmetric) adjustment costs in (3.12). With such costs only large deviations of aY_t from zero induce the firm to alter X. When it decides to change X (and bear the adjustment costs), in this illustration it makes a change that is sufficiently large to obviate the need to alter X again until the path of aY_t crosses zero.

4. *What Do Adjustment Costs Really Look Like?*

We have stressed the difficulties that spatial aggregation presents for inferring the structure and size of adjustment costs. An equally serious aggregation

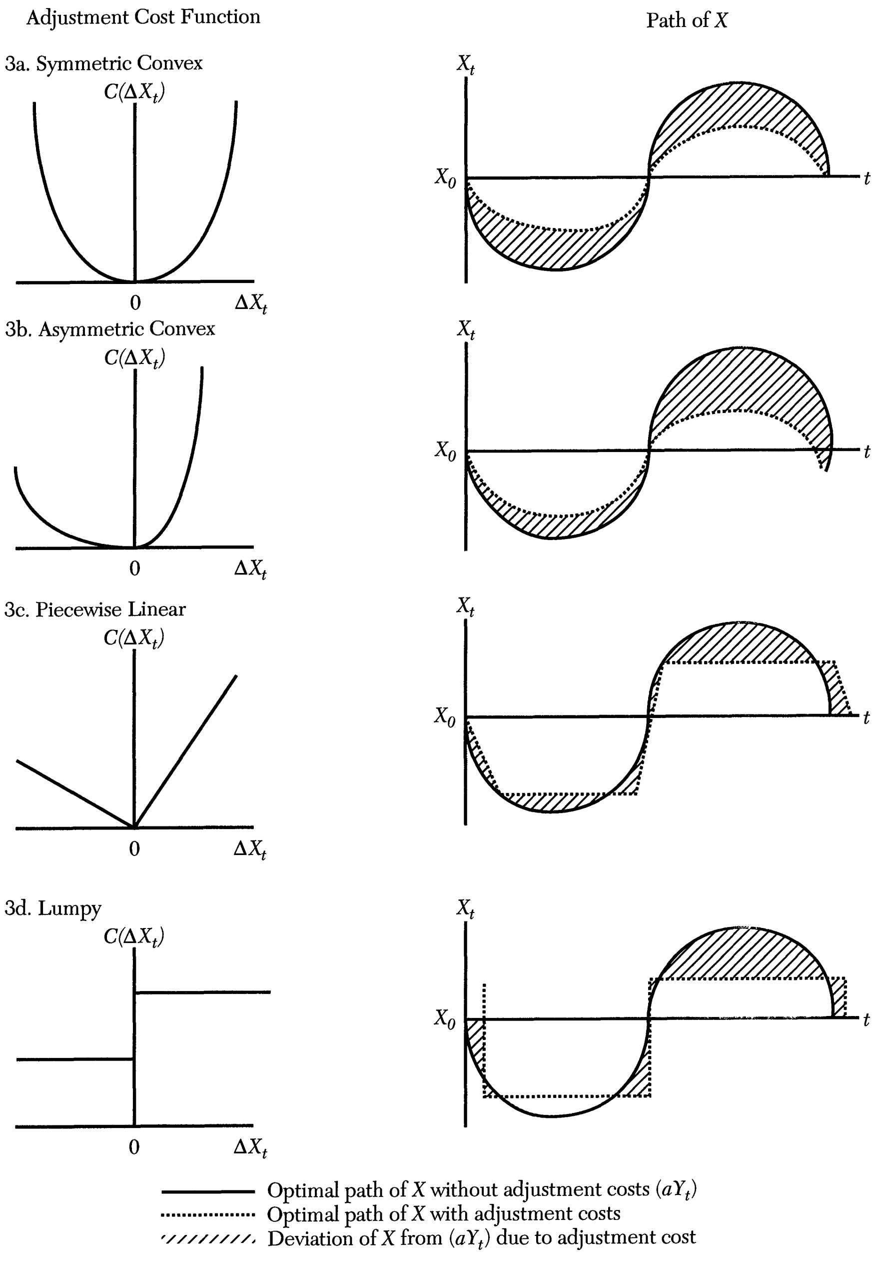

Figure 3. Adjustment Costs and Input Dynamics

problem, though one on which the literature is much more sparse, is that of temporal aggregation. We do not know what the time intervals are between firms' decisions about whether or not to alter factor demand. Indeed, every study of dynamic demand ignores the issue and assumes that the unit of time in firms' decision making is the time interval between the observations in the data that are available (in empirical work) or is some unspecified time interval (in theoretical work). Some researchers implicitly assume that factor demand is revised only once a year, while others assume that revisions occur quarterly or even monthly.

Changing the extent of temporal aggregation does not produce any clear bias to the estimated length of the lag if the true structure of costs is symmetric quadratic, so that the path of dynamic factor demand is as described by (3.5) (Robert Engle and Ta-Chung Liu 1972). But if the underlying structure is not characterized by smooth adjustment, inappropriate temporal aggregation leads to biased estimates of the parameters describing costs and to incorrect inferences about their very structure. Consider two simple illustrations of this problem:

1) Costs are asymmetric convex as in (3.6); but instead of observing behavior at the appropriate intervals we observe the process so that behavior is averaged over two or more intervals. If the mean shock is positive, with a sufficiently large number of intervals and a sufficiently low variance of the shocks the probability of observing a negative deviation of actual from "target" factor demand is very low, as is our ability to infer that adjustment costs are asymmetric.

2) Costs are lumpy and the probability that we observe $X_t = X_{t-1}$ in (3.14b) is φ. The probability that we will observe X changing when we aggregate over M periods is then $1—\varphi^M$. If M is large relative to φ, time series of the length that characterizes most sets of economic data will fail to indicate the presence of any underlying rigidity.

Some firms (for example, universities deciding about hiring tenure-stream junior faculty) make decisions on an annual basis. For them the appropriate degree of temporal aggregation may be to annual observations. In most for-profit firms, though, plans are likely to be revised more frequently than once a year. Especially in larger firms, where projections of product demand are more refined, and in firms where fixed costs of adjustment are lower, higher-frequency data will match the timing of decision making better. How much higher is not clear; and determining the frequency of decision making is a very worthwhile future research project. It is difficult to believe, however, that yearly decision making characterizes very many entities. Quarterly, monthly, or even higher-frequency data should be obtained where those frequencies match what the researcher believes to be the timing of decisions. Panel data sets describing individual firms at higher than annual frequencies are now coming into existence in the United States and several western European countries, and these can and will provide the opportunity to study behavior in a way that matches the timing of firms' decisions more closely. The "problems" that such data seem to generate in the form of seasonality should be viewed as opportunities that require more thought about adjustment and that allow us to understand it better.

Almost all empirical studies of adjustment ignore problems of temporal aggregation and implicitly justify ignoring issues in spatial aggregation by assuming symmetric quadratic adjustment costs. If we believe the common assumption about structure, the results on employment (summarized by Hamermesh 1993a, ch. 7) suggest: 1) The lag in adjusting employment demand is fairly short, with a half-life of perhaps three to six months; 2) Hours per worker are adjusted more rapidly than employment, implying that the costs of adjusting them are less than those of changing employment levels. Taken together this literature implies that adjustment costs for labor are not large. The few studies that have tried to estimate their size directly on aggregate data confirm this conclusion, for they imply that the per-period costs are not much more than one percent of per-period payroll cost. Because the typical fluctuation in these aggregate or industry data averages no more than five percent (Matthew Shapiro 1986; Simon Burgess 1988; Burgess and Juan Dolado 1989), this implies that $C(\Delta L_t) \approx$ 20 percent of annual per worker payroll cost. This is far below what the accounting studies discussed in Section 2 suggested.

The estimates of $C(I_t)$ based on aggregate data are few and vary widely. The evidence based on using such data to estimate models that assume convex costs is that the average lag is around one year in industrialized economies, much longer than that in adjusting labor (as summarized by Robert Chirinko 1993). Many modern empirical studies are very tightly grounded in the q-theory of investment based on symmetric quadratic adjustments costs. The simple assumption about those costs and the restrictions necessary to measure q are, however, inconsistent with the data. Without that assumption one must, as has the rest of the modern literature that uses aggregate data, rely on modeling strategies that generate Euler equations like those derived in Section 3.

The results in this empirical literature are useful for prediction. As in any attempt to aggregate spatially, however, they require a specific assumption (strictly convex adjustment costs) if we are to link the inferences to the behavior of the underlying micro units (Thomas Stoker 1993). The discussion in Section 3 made clear how restrictive that assumption is. Even if we ignore other difficulties in the nature of adjustment (see Section 5), their validity can be ascertained only by confronting them with micro data. Fortunately a growing number of studies have used micro data to estimate factor-demand dynamics. Some of these impose symmetric quadratic costs; but many do not and thus allow inferring the structure of the underlying costs.

If symmetric quadratic costs characterized adjustment, spatial aggregation would not alter the estimates of the adjustment parameter. In fact, however, there is some evidence that this is not the case among those studies that are based on this assumption. Among the studies examining the adjustment of labor demand, Nickell and Sushil Wadhwani (1991) find, as did others using the same annual panel of large British manufacturing firms, that only 20 percent of the adjustment to a shock is made up in one year. Bentolila and Gilles St. Paul (1992), using a similar panel of Spanish manufacturing firms for 1983–88, show that less than one-sixth of the adjustment to an exogenous shock is completed within one year of the shock. Jacques Mairesse and Brigitte Dormont (1985) find adjustment that is nearly so slow for panels of French and German manufacturing firms in the 1970s, though in their panel of American firms nearly five-sixths of the response is completed within a year. Patricia Anderson (1993), who uses a large *quarterly* panel of retail establishments in six American states, finds that most of the adjustment is completed in one quarter.

Research based on quadratic symmetric costs but estimated over annual time series of aggregate and sub-aggregate data indicates that the half-life of the lag in employment demand is about five quarters (Hamermesh 1993a, pp. 253–56). Studies using aggregate quarterly data show an average lag of 1–1/2 quarters. While at this point there are still very few studies that use panels of microeconomic establishment data, at least for the United States the results from such studies suggest that the estimated speed of adjustment is consistently more rapid when such data are used. This difference suggests that temporal aggregation bias does exist in estimating the speed of adjustment and implies that the underlying structure is not well approximated by the assumption of symmetric quadratic costs.

A rapidly growing empirical literature that began in the late 1980s has used microeconomic data to examine employment adjustment without imposing the restriction that changes in the demand for inputs are smooth and symmetric in response to shocks. To save space and give a full impression we summarize this part of the literature on labor demand in Table 1.[8] The Table covers a remarkable variety of different sets of data and a range of industries and economies. While manufacturing is overrepresented compared to its importance in total employment (as is also true in the estimates based on aggregated data), the evidence is not restricted to that sector. Also noteworthy is the restriction of many of the sets of data to annual observations. Unless we believe that the employers represented in these studies make decisions only once per year, temporal aggregation will, as we showed, bias the results toward inferring that factor demand adjusts smoothly. Finally, one should note that it is difficult to obtain data both on employment and on a good set of forcing variables that move employment demand. For that reason some of the studies (Pfann and Verspagen 1989; Craig 1993; and Caballero, Eduardo Engel, and John Haltiwanger 1995) rely on models that are outside the standard approaches described in Section 3.

All the studies using quarterly or monthly data reject the hypothesis of symmetric smooth adjustment of employment in favor of some form of asymmetry (of the kind implied in (3.6) or some other) or of lumpiness. But even the estimates based on annual data also reject that hypothesis and conclude either that there exists some asymmetry or that adjustment costs are lumpy or linear. Moreover, those studies that considered the issue also reject the notion that firms' demand for labor reacts instantaneously to shocks. This literature makes it abundantly clear that *employment adjustment at the micro level is slow and does not follow paths predicted by the approximation of symmetric quadratic costs*. Because the results based on quarterly data imply that linear aggregation is incorrect, this conclusion means that acquiring information on the cross-section variance and higher-order moments of shocks to employment will add to our ability to describe the path of aggregate employment.

It is unclear from this growing literature whether there is one particular nonconvex or asymmetric specification that describes adjustment of employment demand best. It is more likely that firms distinguished by the skills of their workers and the nature of shocks to demand have underlying adjustment costs with different structures. The literature also tells us nothing about the nature of the costs of adjusting worker-hours as opposed to the demand for workers. With the increased availability of firm- and establishment-level data at sufficiently high frequencies to avoid problems of temporal aggregation, and with enough information on other variables to model shocks to demand, research that could shed light on these issues should now begin.

Several studies of the demand for investment have gone beyond aggregate data but have still imposed the assumption of symmetric convex adjustment

[8] In a related study Timothy Bresnahan and Valerie Ramey (1994) use weekly data from a number of automobile manufacturing plants on employment and a variety of other margins along which employers adjust the input of labor. Like the studies in Table 1 they too find evidence of nonconvex adjustment costs.

TABLE 1
STUDIES OF NONCONVEX AND ASYMMETRIC ADJUSTMENT OF EMPLOYMENT USING FIRM-LEVEL DATA

Study	Data	Specification	Result
Asymmetric Adjustment Costs			
Ching-Cheng Chang and Spiro Stefanou (1988)	173 Pennsylvania dairy farms, annual, 1982–84	Switching model using 4 inputs, static expectations	Reject symmetry; eqpt. adjusts slowly only under asymmetry
Pfann and Verspagen (1989)	119 Dutch manuf. firms, annual, 1978–86	Direct estimation of average labor cost as asymmetric function of ΔE	$C(\Delta E^{+}) > C(\Delta E^{-})$, asymmetry parameter signif.
Fabio Schiantarelli and Alessandro Sembenelli (1993)	305 U.K. manuf. firms, 1983–86	Euler eqtns. on ΔE incl. asymmetry term	$C(\Delta E^{+}) > C(\Delta E^{-})$, signif. diff.; each smaller as I is larger
Fidel Jaramillo, Schiantarelli, and Sembenelli (1993)	52 large Italian firms, annual, 1963–87	Euler eqtns. on ΔE incl. asymmetry term	$C(\Delta E^{+}) < C(\Delta E^{-})$, signif. diff
Bresson, Francis Kramarz, and Sevestre (1993)	242 French industrial firms, 1975–83	Euler eqtns. on ΔE, 3 types of workers, incl. asymmetry terms	$C(\Delta E^{+}) \neq C(\Delta E^{-})$ for all 3 types, signif. diffs
Lumpy Adjustment Costs			
Hamermesh (1989)	7 U.S. manuf. plants, monthly, 1983–87	Switching model on ΔE, static expectations	Reject constraint of smooth adj.
Craig (1993)	4 Northwest lumber mills, monthly, 1968–87	Nonparametric estimation of ΔE patterns	Reject pattern implied by smooth adj.
Hamermesh (1992)	Airline mechanics, 7 firms, qtrly., 1969–76	Switching model on ΔE, static expectations, smooth and lumpy costs	Fixed and variable adj. costs both signif.
Caballero, Engel, and Haltiwanger (1995)	U.S. manuf. plants, qtrly., 1972–80	ΔE a function of hours per worker	$Pr\{\Delta E>0\} \uparrow$ with shock to hours
Paola Rota (1994)	3247 Italian firms, 1982–89	Euler eqtn. with smooth and lumpy costs on ΔE	Both types of costs signif.
Linear Adjustment Costs			
Douglas Holtz-Eakin and Harvey Rosen (1991)	Local U.S. governments, annual, 1974–80	Euler eqtn. on $E \Rightarrow$ lags order ≥ 2 if $\uparrow$ marginal costs of adj.	Vector of lags of order ô2 not signif.

costs. Among these much of the interest has been in analyzing the determinants of gross investment, with little attention to what generates lags. Two studies of annual data on U.S. firms (Steven Fazzari, R. Glenn Hubbard, and Bruce Petersen 1988; and Huntley Schaller 1990) estimate that roughly half the adjustment of investment demand to shocks is completed within one year. Mairesse and Dormont's (1985) ten-year panel of U.S. firms suggests much longer lags, though, as do their estimates using French and German ten-year panels. For Britain, however, Richard Blundell et al. (1992) imply around two-thirds of the response of gross investment occurs within one year. Fanny Demers, Michel Demers, and Schaller (1994) use a 35–year panel of U.S. firms to show that this lag is not only long, but also variable with the state of the business cycle.

Simple reflection and our discussion of lumpy costs would suggest that these studies will have misspecified adjustment costs, because it is difficult to believe that the firm's investment in physical capital is smooth. Such reflection should have led students of investment to devote much time to studying it using micro data. The probable length of planning times and other lags suggests that the absence of higher-frequency micro data should not have deterred research. That has not been the case. Rather, there are fewer studies of the dynamics of investment demand using the appropriate microeconomic data than of the dynamics of labor demand. A remarkable early study (Stephen Peck 1974) observed that smoothness is most unlikely in investment in electricity-generating plants and compared models of lumpy costs to those implying symmetric quadratic costs using data on 15 firms over 22 years. Lumpy costs described the pattern of investment far better than quadratic costs at the firm level, an advantage that unsurprisingly disappeared once the data were aggregated across firms for each year in the sample. John Rust (1987) demonstrated for one particular decision maker that replacement investment was not smooth. Mark Doms and Timothy Dunne (1994) charted the frequency distribution of investment in U.S. manufacturing plants and noted that it appears inconsistent with what would result from smooth adjustment. Using long annual panels of firms from the Compustat files Abel and Eberly (1995) construct a model incorporating several of the forms in Section 3, while Steven Barnett and Plutarchos Sakellaris (1995) use these data to estimate a model with generalized nonlinear adjustment. Both models fit patterns of investment at the firm level better than does the standard quadratic model that implies linear adjustment.

Clearly the paucity of micro studies of investment that do not just impose quadratic costs makes any inferences difficult. We could learn a lot about patterns of investment from additional studies of different broad-based panels of firms or establishments. Even so, and like the literature on employment demand, *the few studies of investment demand that permit examining alternative cost structures uniformly find that adjustment is not characterized by symmetric quadratic costs*.

We cannot provide a complete answer to the titular question of this section, as the recent literature is not yet sufficient to tell us how prevalent different structures of adjustment costs are. It has, however, taught us one new, secure fact: Adjustment costs are definitely not uniformly symmetric and convex. Unfortunately, the new literature has shed little light on the magnitude of these costs. Hamermesh (1989) suggests that the lumpy costs of adjustment in the manufacturing plants he studied are so large that a shock must alter employment demand by 60 percent before employment is changed. The employment of airline mechanics discussed by Hamermesh (1992), however, is changed once shocks alter demand by more than five percent. Fabio Schiantarelli and Alessandro Sembenelli (1993) imply that the cost of increasing employment is almost one percent of payroll cost, while an equal-size cut in employment raises costs by only 0.2 percent of payroll cost. Again assuming employment fluctuations averaging ± 5 percent per annum, this result corroborates the inference from the few studies using aggregated data that adjustment costs of employment are below one-fourth of annual payroll costs.

The evidence on the size of adjustment costs induced by investment in plant and equipment differs in the two studies offering such information. Frank Lichtenberg (1988) harks back to the early theoretical literature by including internal costs of adjustment directly in the production function. He uses a nine-year panel of over 1000 U.S. manufacturing establishments to infer that these costs reduce current output by about 30 cents for each dollar of investment. Because capital's share of manufacturing value added is roughly one-third, his evidence suggests that adjustment costs in continuing plants in that industry are as large as the cost of capital services. On the other hand, the complex adjustment-cost model of Abel and Eberly (1995) suggests that these costs are no more than 12 percent of the cost of investment. More work clearly needs to be done on this issue.

5. *Why Is Adjustment Slow?*

The initial interest in adjustment costs arose from the hope that they might justify the econometric success of introducing lagged dependent variables in equations describing factor demand. Implicit in the specifications (2.2) are the assumptions that adjustment costs can be linked uniquely to the costs of altering a particular input X; that slow adjustment of input demand is due to these costs; and that we can distinguish gross from net costs. These assumptions are perfectly reasonable; but whether they are useful for understanding why the adjustment of stocks of capital and of employment by individual firms is slow, asymmetric, and not smooth is a complex issue.

There are three reasons why we might observe slow adjustment of a single input using microeconomic data even though firms' profit functions are not characterized by adjustment costs of the types discussed in Sections 3.B–D. One possibility is that it simply takes time between the decision to add to an input and the date when it becomes productive. These patterns exist in Thomas Mayer's (1960) survey indicating there is a two-year lag in U.S. manufacturing plants from the start of plans to the completion of construction. While this evidence suggests that the time to build structures is no less consistent with microeconomic data than are adjustment costs, long and discrete lags seem less consistent with the market for much capital equipment; and the concept seems nearly irrelevant in describing the demand for labor.

A second alternative explanation is that the observed pattern of adjustment results from firms' responses to demand shocks and that we have failed to specify expectations about those shocks satisfactorily in our models. There may be some combination of shocks and the formation of expectations about them that generates the behavior we observe at the firm level. Without careful comparisons of product and input demand at the firm level we cannot rule this out. But the evidence available thus far (in Hamermesh, 1989, and several later studies) suggests that this explanation is not satisfactory.

Yet another alternative is that the typical firm's objective function is more complex than that included in (3.4), and the complexity means that we cannot identify adjustment parameters separately from the parameters of that function. This is quite possible; but regardless of the nature of static costs, they alone would not generate slow adjustment. Something that links current and future decisions about input demand is required to produce sticky input demand.

In the end, adjustment costs must be viewed as only a modeling device. They are not necessarily the only way of generating observed behavior; but they, and particularly the more complex forms discussed in Sections 3.B–D., provide a simple description of firms' behavior that is consistent with a growing array of evidence on the demand for inputs.

Whether our assumption that slow adjustment in a particular input X_i results from costs directly associated with changes in it alone is correct is not clear, however. If adjustment costs stem from one input we will observe slow adjustment of other inputs. Assume, for example, that there are only two inputs, labor and capital, that firms have perfect foresight about the future paths of input prices and product demand, and there are costs only of adjusting labor. Then the firm projects its demand for capital services as:

$$F_K(K_t, L_t) = r_t. \quad (5.1)$$

Equation (5.1) is not the usual standard static marginal productivity condition, for if adjustment costs are quadratic labor will not be employed at the long run profit maximizing rates once a shock has occurred. In response to a negative demand shock employment will be adjusted downward slowly; because of this stickiness the marginal revenue product of capital services will be greater than if labor were also a variable input. The demand for capital services would not be cut instantly to the new, lower long run profit maximizing level, but would instead decrease over time as employment decreases.

This problem has been widely recognized, as has the need to specify an $N \times N$ matrix of adjustment costs for all N inputs into production. The diagonal terms in the matrix would indicate the costs attached to adjusting each input independent of the effect on others; the off-diagonal terms indicate whether a dynamic disequilibrium demand for one factor hastens or retards the adjustment of others. Two factors are said to be *dynamic p-complements* if slow adjustment in the demand for one generates additional slow adjustment in the demand for the other. They are *dynamic p-substitutes* if, when the demand for one input adjusts more slowly, the adjustment of demand for the other input is speeded up.

This approach to the interrelationships among the costs of adjusting inputs has generated a substantial empirical literature, beginning with M. I. Nadiri and Sherwin Rosen (1969). They and succeeding authors have specified and estimated systems of dynamic input-demand equations of the sort:

$$X_{it} = \lambda_{ii} X_{i,t-1} + \Sigma_{k \neq i} \lambda_{ik} X_{k,t-1} + X^*_{ik},\ i = 1, \ldots, K, \quad (5.2)$$

where the λ_{ik} are the elements in the matrix of adjustment parameters. Systems ranging from two inputs (the capital stock and the number of workers) up to as many as nine inputs (Robert Rossana 1990), including new and unfilled orders, various types of inventories and various dimensions of labor services, have been estimated. In many cases the off-diagonal elements of the matrix λ_{ik} suggest the existence of significant dynamic p-substitution and complementarity; but specifying models like (5.2) instead of single-equation models does not appear to alter greatly the inferences about the relative magnitudes of the λ_{ii} associated with different inputs.

The difficulty with this inference is that this bit of literature consists entirely of estimates of models based on highly aggregated (two-digit SIC industries or higher) data using models specified on the assumption that all costs of adjustment are quadratic and symmetric. As we saw in Section 4, that assumption is wrong, at least as a generalization; and without micro data, we cannot know whether inferences about the relative unimportance of dynamic interrelationships among inputs for their time paths would be altered if we specified adjustment costs more generally. At this point a fair conclusion is that the restriction of empirical work in terms of specification and choice of data means we know very little about how adjustment costs associated with one input affect the paths of others, or even whether slow adjustment in one input truly stems from costs directly associated with it.

Another difficulty in inferring why we observe these paths of adjustment of inputs is that it may be difficult to distinguish between gross and net costs of adjustment. For example, we may conclude from slow adjustment of investment demand in response to exogenous shocks that the costs are gross because we observe only gross investment; but the slowness may just as well arise from net costs of adjusting the level of capital services that we do not observe. Similarly, we may see that employment demand adjusts slowly; but is that because the costs are net, as the data would lead us to infer; or is it instead that gross costs produce slow adjustment in levels of employment? Without knowing the source of the costs we have little hope of using estimates of parameters describing the lag structures that we specify, no matter how sophisticated they are, to extrapolate to the likely effects of policies that impose gross or net costs of adjusting inputs.

If the variance of XO is tiny relative to that of XI in (2.1), it will be very hard to distinguish the sources of slow adjustment in X, as the covariation in ΔX and XI will be nearly perfect. We do not have good information on the relative variances of XI and XO, but we do have data on their levels. In France, Germany, and the United States during the 1970s the rate of net investment averaged 1/3 to 1/2 the rate of gross investment (Mairesse and Dormont 1985). In eight American states from 1978–84 (Anderson and Bruce Meyer 1994) total separations averaged 23 percent per quarter, while employment in the average expanding firm grew by seven percent and in the average declining firm fell six percent. Data for the Netherlands in 1988 and 1990 covering annual changes (Hamermesh, Hassink, and Jan van Ours 1996) suggest that the sum of XI and XO was 22 percent, while growing firms added four percent to employment and declining firms dropped two percent. Taken together, the evidence indicates that gross flows of both capital and workers are larger than net changes, but that the latter are not tiny. Careful exploitation of the data may thus allow inferring the relative importance of the two sources of slow adjustment.

Regrettably little effort has been made thus far to infer how important the two types of costs are. Most empirical research on adjustment of the demand for capital is based on gross investment. Results by Mairesse and Dormont (1985) do, however, indicate that the lags in individual firms' adjustment of the stock of capital differ from those of gross investment (alternatively, the time path of replacement investment in response to demand shocks differs from that of net investment). Most research on the dynamic demand for labor focuses on the path of the level of employment. Yet estimates of models that try to infer the relative magnitudes of the two types of cost (Hamermesh 1995) imply that the gross costs of adjusting labor demand are at least as important as net costs. These very sparse results suggest that research on the dynamics of factor demand needs to focus more closely on what types of costs are producing the dynamic behavior that we happen to observe in the data that come readily to (econometric) hand.

6. *Implications for Macroeconomic Fluctuations*

Because the original motivating interest in firms' dynamic adjustment stemmed from concern about aggregate employment and investment, the conclusion that adjustment costs are not characterized by the symmetric quadratic structure that is usually assumed should modify how we think about aggregate behavior. How, for example, does the aggregation of individual agents facing asymmetric or linear or lumpy adjustment costs generate differences in the paths of aggregate employment and investment in response to external shocks? How do individual firms' input decisions differ between business-cycle peaks and troughs if negative aggregate demand shocks are larger and less frequent than positive ones? How do aggregate paths differ depending on the extent of heterogeneity of the shocks compared to the heterogeneity among the agents? How do differences in the underlying adjustment cost structures determine the paths of business cycles? Most generally, why do all the theory and tests for the underlying structures and sizes of adjustment cost matter for macroeconomic behavior?

A number of studies have shown that employment changes at the aggregate level are asymmetric over the business cycle (recently Steve Davis and Haltiwanger 1990). Yet Caballero (1992) showed that in the absence of aggregate fluctuations, or when those interact with idiosyncratic shocks, adjustment costs at the firm level do not necessarily imply asymmetric responses of aggregate K and E. This observation leaves unanswered the question of how the aggregate asymmetries arise. One possibility is that aggregate shocks themselves are asymmetric, with negative shocks being larger and less frequent. If this explanation were correct we would observe the same extent of asymmetry in the path of output that we observe in the path of employment. In fact, the asymmetry in aggregate output cycles is much less than that in inputs (J. Bradford De Long and Summers 1986).

Another possibility, based on the costs of adjusting inputs that we have discussed, is that aggregate shocks trigger adjustment of factor demand only in some fraction of firms, while in others no adjustments are made. Investment in structures may be characterized by gestation lags, employment may be adjusted in a lumpy fashion, while investment in equipment may be characterized by both. How these two types of adjustment relate at the firm level, and how they aggregate, are important questions that have not been answered. These considerations do, however, suggest that a model that describes input dynamics at the aggregate level must contain an asymmetric propagation mechanism for at least one input. One reasonable candidate is a specification like that in (3.6). Real business cycle models that attempt to explain aggregate facts by the general-equilibrium interactions of a few representative agents usually focus on contemporaneous correlations between output and the levels and prices of inputs. These models frequently fail to reproduce the frequently large dynamic correlations that are often asymmetric between leads and lags. One remedy for this failure, as shown by Xavier Fairise and François Langot (1994) using a model of the U.S. economy, is to add adjustment costs.

One microeconomic justification for including adjustment costs in aggregate general equilibrium models is provided by matching models such as that of Dale Mortensen and Christopher Pissarides (1994). Their model was developed to explain the microeconomic evidence (Davis and Haltiwanger 1992) that job creation and job destruction in U.S. manufacturing firms are negatively correlated over the cycle, that job destruction is more volatile over the business cycle, and that the absolute sum of the two in the U.S. is countercyclical.[9] Incorporating heterogeneous matching functions into the RBC models with the specific purpose of simulating the dynamics of the cyclical behavior of factor inputs is an extremely difficult task, but a representation that specified asymmetric adjustment costs might provide a good approximation. A second justification is to reflect the costs of adjusting the efficiency of labor. Once employment decisions are taken, the only way that adjustment can occur is if employers vary the demand for effort (Craig Burnside, Martin Eichenbaum, and Rebelo 1993). That variation can be asymmetric, so that, for example, marginally increasing a worker's effort may be more costly than allowing a marginal decrease in effort.

The microeconomic evidence for nonconvexities in the costs of adjusting the demand for workers that was summarized in Table 1 has led to macroeconomic models of dynamic factor demand that contain more realistic microeconomic foundations. These models aim at giving a more accurate description of the microeconomic market structure, including heterogeneity of agents, idiosyncratic uncertainty and the lack of coordination, without losing their aggregate predictive power. They include dynamic (S,s)-behavior (Caballero and Engel 1991), which can be regarded as a special case of the lumpy adjustment costs in (3.12).

The adjustment-hazard model (Caballero and Engel 1993) allows for constant or increasing hazards of altering factor demand and seems the most promising for building from microeconomic factor-demand dynamics to explaining aggregate fluctuations in input demand. Let a firm $i \in [0,1]$ that would have used X_{it}^* if the factor market were frictionless employ X_{it} units of input at period t. The deviation from its target input is defined as:

$$z_{it} \equiv \log X_{it} - \log X_{it}^* . \qquad (6.1)$$

A firm's adjustment policy can be modeled as an adjustment hazard function $\Lambda(z_{it})$, which expresses its propensity to adjust as a function of the deviation z_{it} from its target input level in a given time period. If this function is constant we may infer that the firm faces quadratic adjustment costs. If the firm's propensity to adjust is positively related to the absolute size of z_{it}, the hazard function is increasing and costs are nonconvex. At the aggregate level the responses of inputs to shocks are then nonlinear and dependent on history. This dependence arises from the initial cross-section distribution of the z_{it}, whose ontogeny is in turn influenced by aggregate shocks, idiosyncratic shocks and the proportion of firms that have adjusted in each past period.

The asymmetric increasing hazard model can be described by:

$$\Lambda(z_{it}) = \begin{cases} g^+ \text{ iff } z > 0 \\ g^- \text{ iff } z < 0 \end{cases} \qquad (6.2)$$

[9] This countercyclicality is specific to the U.S. In Italy, for example, the opposite pattern is observed (Bruno Contini and Ricardo Revelli 1992).

where $g^+ \equiv g_0^+ + g_1(z_{it})^2$ and $g^- \equiv g_0^- + g_1(z_{it})^2$, with the $g_i > 0$ being parameters of the hazard function. Asymmetric hazards imply that a firm's propensity to change its demand for inputs is not the same in absolute terms if the random shocks are of the same magnitude but have opposite signs. The aggregate change in input demand induced by a random shock is nonlinear but can be obtained analytically.

When a random shock raises the target level of the input in this model, some firms will increase their stock of X in a lumpy sort of adjustment, while other firms' demands are unchanged until further shocks in the same direction trigger their responses. If $g^+ < g^-$, lumpy upward adjustments are less likely to occur than lumpy downward adjustments in response to equal-size positive and negative shocks, because at any given time the fraction of firms with a high propensity to add the input after a positive shock is smaller than the fraction of firms with a high propensity to cut input demand after a negative shock. Nonconstant adjustment hazard functions can thus generate aggregate cyclical asymmetry in the demand for factors of production.

The appeal of the asymmetric hazard approach on theoretical grounds is that it does not require the assumption of a representative agent to describe input dynamics at the aggregate level. Given the microeconometric evidence of the dubious nature of that particular assumption, this is a compelling argument for using this approach or one like it. On empirical grounds the appeal of the model, or of the lumpy or linear models of adjustment costs on which it is based, is the evidence that substantial increases in our ability to explain aggregate employment fluctuations and the path of aggregate investment are obtained when we have information on the cross-section dispersion of cost or product-demand shocks (as shown by Caballero, Engel, and Haltiwanger, 1995, for employment, and Abel and Eberly, 1995, for investment).

One difficult and as yet unsolved problem with this more realistic and useful model is that the target input level, represented in part by the constant terms in the asymmetric hazard function that differ between positive and negative shocks, is specified in an ad hoc way. The target level depends on the structure of input prices facing the firms in the factor market and on the distributions of idiosyncratic and aggregate shocks. This difficulty does not detract from the model's value for studying aggregate dynamics, its main purpose; but it does mean that the representation is as yet incomplete.

7. *What Needs to Be Learned?*

The vast literature on dynamic factor demand has been organized around the concept of costs of adjustment. The standard assumption has been that these costs are convex and symmetric. This is the basis for the macroeconomic models embodying rational expectations that have become the staple of graduate courses since the late 1970s. The assumption has underlain a huge empirical literature, based mostly on highly aggregated data, that has examined, among others, such issues as the cyclicality of labor productivity, the dynamics of investment demand, and the timing of the effects of energy price shocks.

The assumption is not supported by microeconomic data: On a variety of data sets a rapidly growing body of empirical research has demonstrated that other functional forms describe the technology of adjustment of individual inputs into production better. No doubt some firms' behavior may be described by symmetric quadratic costs; but on every one of the sets of microeconomic data in which it has been examined this standard assumption is dominated by some alternative that we discussed in Sections 3.B-D. This suggests that the assumption is far from universally correct. The immense literature that imposes what was originally viewed as merely an approximation is inconsistent with the admonition that forms the epigraph to this survey, as it is based on an assumption that is by no means universally valid.

There is nothing wrong with simplifying assumptions provided they do not restrict our understanding of what we are trying to study. At this point, however, maintaining the assumption of symmetric convex adjustment costs restricts our ability to understand a variety of economic phenomena. For example, knowing that adjustment costs are more complex than we previously thought has allowed us to improve predictions of the paths of aggregate employment and investment based on knowledge of the cross-section dispersion of underlying shocks. Simple aggregation of the behavior of a representative agent does not predict so well. As another example, knowing that costs are not always symmetric and convex leads us to a better understanding of the likely impacts of changes in such labor-market policies as restrictions on layoffs than we obtain if we rely on the standard assumption. In sum, the convenient approximation detracts from our ability to provide useful discussions of macroeconomic behavior and microeconomic policies.

The implications of this new view of factor-market dynamics for analyzing factor markets, and especially for aggregate adjustment, are just beginning to be analyzed. It is clear that adjustment is slow; but it is unclear which of a large variety of sensible alternative descriptions of adjustment costs best characterizes firms' behavior. Most likely no single model is uniformly applicable, any more than the standard model is. Having torn down the old approach, we have not yet replaced it with a new consensus for use in modeling and estimation. The task of those who study firm-level behavior is to examine the prevalence of various more general forms of adjustment costs. We cannot expect to have a directory of such structures, any more than we can expect to have a census of people's utility functions; but we can expect to develop some feel for the relative importance of different general descriptions of adjustment costs.

An important first step will therefore be to discover the correlates of the structures of adjustment costs in order to learn how widespread each potential description of these costs is. Simply running "horse races," as much of the empirical literature that has destroyed the old assumption has done, does not inform us about the relative importance of alternative structures. We need empirical studies that include (and hopefully nest within a general model) several specifications of these costs. As the existing research indicates, such studies must be based on microeconomic data; but with the large sets of long panel data that are now becoming available it should be possible to infer the kinds of industries and perhaps the workers' and firms' characteristics that are associated with different structures of adjustment costs.

With knowledge of how to characterize the structure of adjustment costs we should be able to infer how large these costs are and how they vary cyclically. Existing estimates, based either on a few accounting studies or on demonstrably inappropriate aggregated data, lack a basis in microeconomic theory. Discovering the size of adjustment costs and how these too vary by industries' and workers' characteristics should be high on anyone's research agenda in the study of factor demand.

In analyzing policies that affect the cost of labor we use estimates of demand elasticities—underlying structural parameters—to predict how proposed policies will affect employment. We base discussions of the potential impacts of changes in investment credits and depreciation rules on estimates of the parameters describing the demand for investment goods. There have been some attempts to infer the ex post impacts of policies that are believed to affect adjustment costs by comparing estimates of λ in (3.4) across countries or within a country over time (most recently by Katharine Abraham and Susan Houseman 1993); but there has not been any progression from theory to structural estimation to evaluation of the kind that exists in studying policies that affect long-run input demand. If research in this area advances as we indicated above, we should finally obtain a theoretical and empirical basis for predicting the impacts of proposed policies. We should be able to take particular proposals that might affect, for example, the hiring or separation costs of labor, or allowable depreciation rates on capital, and infer how they would change the time path of employment or investment.

The representative agent model that has been used to analyze the behavior of firms on an aggregate level should now be regarded as passé. We need to learn how (stochastic) aggregation maps microeconomic behavior into macroeconomic relations. An already fruitful path that gives promise of yielding substantial additional insights is to use microeconomic panel data to measure the sources, structures, and relevance of adjustment costs and how they are affected by aggregate and idiosyncratic uncertainty and the nature of shocks.

In the 1960s and early 1970s the pages of leading economics journals were replete with studies aimed at improving the estimation of macroeconometric forecasting models. With a very few exceptions (such as Fair 1994) these have disappeared from the attention of academic economists. The new learning about adjustment costs that we have outlined here should be incorporated in such models. Aside from improving their ability to predict input dynamics, it can also give them a sounder basis in economic theory.

Several recent studies in other areas (Alan Blinder 1991; Truman Bewley 1995) illustrate how insights into macroeconomic behavior can be obtained from direct observation of individual agents by informed observers (economists), as have Pfann and Verspagen (1989) in studying adjustment costs. By expanding our direct observation of what businesses do and how managers' thought processes condition those actions, we should be able to gain additional insights into the nature of adjustment costs. This approach means combining the accounting studies discussed in Section 2 with the powerful organizing ability of economic theory to provide information on the size of adjustment costs and their implications for economic behavior.

Adjustment costs are central to a large part of economic analysis. We are only now beginning to think about them instead of relying on convenient but untested assumptions. That thought and the measurement that it has engendered have generated an understanding of the role of adjustment costs in input demand and their implications for macroeconomic adjustment. Most important, they have placed a bound on our current state of ignorance and a realization of the research that should be done in this area. The current state of knowledge is far behind what we know about the long-run demand for inputs; but at least the kinds of research that need to be undertaken and their importance have become clear.

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