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7 Research and Development Expenditures and Labor Productivity at the Firm Level: A Dynamic Model

M. Ishaq Nadiri and George C. Bitros

7.1 Introduction

The importance of innovative activities to the development and growth of the aggregate economies, various industries, and firms has been clearly established (see Kamien and Schwartz 1975). Issues such as the determinants of R and D expenditure, the rate and process of dissemination of innovative activities, the rates of return on R and D investment, the role of uncertainty in the undertaking of these efforts, and finally the industrial and organizational aspects of innovative activities have been the subject of numerous investigations.[1] Though there is considerable uncertainty about the quantitative evidence, the importance of research and development efforts in increasing productivity and developing new products has been generally accepted. However, one issue that has not received sufficient attention is the integration of the demand for research and development expenditure of the firm with its demand for conventional inputs such as labor and physical capital. The need for such undertakings is clear; R and D, like expenditure on plant and equipment and labor, is an input to the production process and therefore an integral part of the overall decision framework of the firm.

The primary purpose of this study is to investigate the determinants of research and development expenditure in the context of a general

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1. Some examples of such studies are Baily (1972), Grabowski (1968), Kamien and Schwartz (1974, 1975), Mansfield (1968), Mansfield et al. (1971), and Scherer (1965).

dynamic model of a set of input demand functions. The consequences of research and development for other inputs and the impact of changes in demand for labor and physical capital on R and D decisions are treated together using a disequilibrium adjustment model of input demands. Within the context of this model the following issues are analyzed: (*a*) the short-run effects of changes in output and relative prices on demand for innovative activities, measured by stocks of R and D expenditure, employment, and capital stock; (*b*) the effects of the excess demand in any of these inputs on the short-run demand for the other inputs; (*c*) the effects of research and development and plant and equipment expenditures on labor productivity in the short, intermediate, and long runs; and (*d*) the responses of the inputs of firms of different asset sizes to changes in relative prices and output changes and the pattern of interactions among their inputs over time.

The main results of this study can be summarized briefly:

1. Changes in output and relative input prices significantly affect, in the short and long runs, the firm's demand for labor, research and development activity, and capital goods.
2. The transitory or distributed lag responses of the inputs to changes in output and relative prices are interdependent, i.e., a dynamic and asymmetrical feedback system is operative among the input responses which traces the adjustment of the system of input demands toward its long-run equilibrium.
3. Substantial differences exist among the cross-section of firms in their employment, research and development activity, and physical capital accumulation. Also, there is evidence of systematic overtime differences in their demand for labor, research and development activities, and capital goods.
4. Research and development investment exerts significant influence on the short and long-run behavior of labor productivity.
5. Finally, no discernible differences in input demand functions were found when firms in our sample were classified by the size of their assets.

The plan of the study is as follows: The rationale of the disequilibrium approach to the analysis of input demands is described in section 7.2. An example to illustrate the issues is provided and the outlines of the structure of the model are stated in this section. In section 7.3, the estimating equations, the characteristics of the data, and some estimation problems are described. The structural estimates of the model using data for sixty-two firms for the period 1965 to 1972 are presented and discussed in section 7.4.1. In section 7.4.2 the structural estimates of the model fitted to samples of firms classified by their asset sizes are presented. The stability of the model is also examined. In section 7.5, the cross-sectional differences among firms in their demand for inputs are noted and the overtime differences among input demands are analyzed. Furthermore, the long-run output and price elasticities of employment, research and development, and capital stock are discussed in this section. Also, the short, intermediate, and long-run effects of research and development on labor productivity are examined. The summary and conclusions are stated in section 7.6, followed by an appendix where the sources of data, construction of the regression variables, and the names and classification of the firms by the size of their assets are reported.

7.2 The Rationale for a Dynamic Disequilibrium Model

Existing cross-section and time series models of the determinants of R and D behavior assume fixed stocks of capital and labor. Also, no allowance is made in the employment and investment literature for the fact that a firm's R and D activities will affect its cost structure and thus its demand for labor and capital. That is, decisions with respect to the conventional inputs will be influenced depending on when and how vigorously the firm engages in innovative activities. In turn, a firm's demand for research and development effort will be affected by the magnitudes and characteristics of its capital and labor. In this type of interactive process, all the inputs are essentially variable and are only differentiated from each other by the *degree* of their flexibility or adjustment over time.

The dynamic model described below permits interaction among these inputs over time. The main feature of the model is that the disequilibrium in any of the inputs has a spill-over effect on demand for other inputs in the short run, while in the long run all excess demands disappear and the spill-over effects vanish.[2] However, in the very short run, as the firm attempts to adjust its stocks of inputs it will increase the utilization of its existing stocks to meet current demand. As the stock adjusts, the utilization rates return to their optimum levels.

7.2.1 An Example

To illustrate the nature of dynamic interactions among time paths of inputs, consider a simple two-factor example. Suppose the production function is $x = f(y_1, y_2)$, where x is output, y_1 and y_2 are inputs, and f has the usual continuity properties. Two isoquants are illustrated in figure 7.1. The dotted line AB is the locus of efficient expansion points

2. We recognize that the dynamic input and output paths are jointly determined, contingent on future product price expectations. But their joint estimation requires a full market theory not yet available. Therefore, we set the limited goal of estimating optimum input paths consistent with an optimum and given output path. This allows us to concentrate on interactions among changes and on factor substitution.

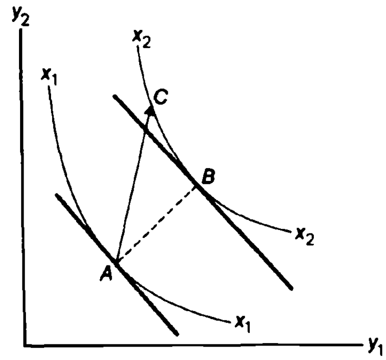

Fig. 7.1 Interactions among Time Paths of Inputs

along which total costs are minimized and is derived in the conventional way. Though this may be an adequate description of long-run behavior, there is plenty of evidence to suggest that firms do not remain along *AB* at every moment, and several explanations for this divergence have been offered. Most important, in addition to direct rental charges of factors, there are costs involved in changing their levels; that is, there are substantial transactions costs, and these must be viewed as additional investment costs if they are to be undertaken. There are search, hiring, training, and layoff costs and associated morale problems among workers. Similarly, there are searching, waiting, and installation costs in purchasing new capital goods, and there are adjustment costs associated with changing the level of the R and D activities such as acquisition of the appropriate facilities, search cost in hiring and training of scientists and engineers, etc. If initial input values deviate from their long-run equilibrium levels, existence of these costs implies that optimum adjustment paths to equilibrium are not instantaneous. Since exogenous variables are generally subject to change and uncertainty, these costs often make it profitable for firms to engage in hoarding of input stocks.

The conventional way of incorporating adjustment costs is the well-known partial adjustment model:

$$(1) \qquad y_{1t} - y_{1t-1} = \beta(y^*_{1t} - y_{1t-1}), \quad 0 < \beta < 1,$$

where y^*_1 is the desired level of y_1 as defined by *AB* and β is the adjustment coefficient. Suppose the firm wants to increase output to x_2, given initial condition *A* in figure 7.1. Equation (1) implies an immediate move from *A* to (say) *C*, with convergence along the new isoquant to the new equilibrium point *B*. The diagram indicates a corresponding and implied adjustment path for y_2.[3] In general, two independent adjustments imply additional hypotheses concerning the role of the production function during the adjustment period. There are two possibilities:

i) If the production function constraint always holds as an equality, independent adjustments imply an output decision function, which may not be optimum.

ii) If output is taken as exogenous, two independent specifications mean that firms must be off their production functions, i.e., they must be capable of producing more than they actually do during the adjustment period.[4]

An intermediate position is also possible—that is, to assume output to be exogenous, but input adjustments are specified to be interrelated. For example, a generalization of equation (1) is

$$(2) \qquad \begin{bmatrix} y_{1t} - y_{1t-1} \\ y_{2t} - y_{2t-1} \end{bmatrix} = \begin{bmatrix} \beta_{11} & \beta_{12} \\ \beta_{21} & \beta_{22} \end{bmatrix} \begin{bmatrix} y^*_{2t} - y_{2t-1} \\ y^*_{1t} - y_{1t-1} \end{bmatrix}.$$

This incorporates exogenous output and allows firms to remain on their production functions during the adjustment process, since input adjustments are not independent.[5] Refer again to figure 7.1. If the true adjustment path is described by ACB, β_{21} and β_{22} must be sufficiently positive to initially push y_2 above its ultimate value. This overshooting sets up forces that ultimately decrease y_2 to its equilibrium value at B. The net values of β_{11} andβ_{12} must be positive for y_1 to increase monotonically to its equilibrium at B. Obviously, there must be restrictions on the B_{ij} to insure that the firm remains along isoquant x_2x_2.

7.2.2 The Model of the Input Demand Functions

Assume that the firm minimizes costs subject to a Cobb-Douglas production function with three inputs: labor (L), capital stock (K), and stock of research and development activities (R). The input and

3. Assume f is Cobb-Douglas, $x = (y_1)^a(y_2)^b$. The demand for y_2 may be derived from a logarithmic form of equation (1) and from $y_2 = (x)^{1/b}(y_1)^{-a/b}$. It is given by

$$y_{2t} = (x_t)^{1/b}(y_{it})^{\beta}(y_{1t-1})^{(1-\beta)^{-a/b}}.$$

4. Nerlove (1967). Nerlove adopts the second approach. In his model, firms react not to observed values of output and relative prices, but to forecasts of unobserved (trend-cycle) components. Desired and actual output are identical, but firms may be off their production functions.

5. It is interesting to note that a similar hypothesis has been proposed by Brainard and Tobin (1968) in the related context of portfolio adjustment among assets. These authors have assumed the wealth path to be exogenous and have addressed themselves to determining optimum adjustments of various assets consistent with that path.

output prices are assumed to be exogenously given. More formally, the general problem considered is to minimize costs,

$$C = wL + cK + rR \tag{3}$$

subject to the production function

$$Q = AL\alpha_1\ K\alpha_2\ R\alpha_3\ U\alpha_4\ e^{\lambda t}, \tag{4}$$

where w, c, and r are respectively the user costs associated with employment, stock of plant and equipment, and stock of research and development. Q is the level of output, A is a constant, α_1, α_2, and α_3 are the long-run output elasticities of the inputs, and λ is the rate of disembodied technical change. We have assumed that the input utilization rates are functions of an overall rate of utilization, U. Also note that the utilization rate U does not explicitly enter the cost function, but implicitly through the rate of depreciation, δ, of capital stock. Depreciation depends on the rate of utilization, U, as well as time, i.e., $\delta = \delta(U,t)$.

The user costs are defined to include the purchase price, the opportunity costs of funds, depreciation expenses due to utilization and passage of time, tax considerations, and capital gains. For example, the user costs of capital goods can be stated as

$$c = \frac{P_k(r+\delta)(1-\bar{k}-v_z+v_z k')}{(1-v)},$$

where P_k is the deflator for capital goods; r is the cost of capital, measured as $r = i - (\dot{P}/P)^e$, where i is long-term interest rate and $(\dot{P}/P)^e$ is the expected change in prices; δ is the depreciation rate; P and $\dot{P}$ are the level and change in general price level; $\bar{k}$ is the Long tax credit amendment; k' is the effective rate of tax credit; z is the present value of depreciation; and v is the corporate tax rate. The user costs for labor services and for research and development efforts are in principle similar to c. The Langrangian method for minimizing costs (3) subject to the production function (4) will yield the long-run solution of the determinants of the inputs.[6] That is,

$$\begin{aligned} y^*_1 &= L = g_1(x^*, \bar{P}),\\ y^*_2 &= R = g_2(x^*, \bar{P}),\\ y^*_3 &= K = g_3(x^*, \bar{P}),\\ y^*_4 &= U = g_4(P), \end{aligned} \tag{5}$$

where $\bar{P}$ is a vector of the relative prices of inputs and the coefficient of x^* is $1/\rho = (\alpha_1 + \alpha_2 + \alpha_3)$, the reciprocal of returns-to-scale pa-

6. See Nadiri and Rosen (1973), pp. 19–21, for derivation of these expressions.

rameter. Assuming that the adjustment cost of each input is proportional to the gap between its long-run equilibrium and actual levels and is also affected by the disequilibrium of the other inputs, it can be shown that the approach to the long-run equilibrium of the system of inputs is approximated by the following set of difference equations (Nadiri and Rosen, 1973, pp. 24–25).

$$y_{it} - y_{it-1} = \sum_{j=1}^{4} \beta_{ij} [g_i(x_t, \bar{P}_t) - y_{jt}] + v_{it}, \quad (i=1, \ldots, 4), \tag{6}$$

where β_{ij} is a nondiagonal matrix of adjustment coefficients and $v_1, \ldots, v_4$ are random terms with zero means and variance-coverance matrix Ω. From the generalized adjustment model (6) we can find (*a*) the short-term impact of changes in output and relative input prices, (*b*) the transition or distributed lag patterns of the inputs to a change in these variables, and (*c*) the long-run price and output elasticities of the inputs. Since the technical details of these problems are discussed elsewhere (Nadiri and Rosen 1969), we may state that the short-term transitory responses are calculated by computing $[I - (I - B)\,Z]^{-1}$ and the long-run elasticities by calculating $A[I - B]^{-1}$; $B = [\beta_{ij}]$ is the nondiagonal matrix of adjustment coefficients, Z is the lag operator, and A is the matrix of the coefficients of the exogenous variables.

7.3 Estimating Equations: Data and Estimation Problems

The model specified in section 7.2 has been estimated using cross-section and time series data on sixty-two firms for the period 1965–72. The main source of our firm data is the Compustat tapes. The sixty-two firms are drawn from five industries: five from Metal extraction (SIC 10), twenty-eight from Chemicals and allied products (SIC 28), twelve from Nonelectrical machinery (SIC 35), eight from Electrical equipment and supplies (SIC 36), and nine from instruments (SIC 38). Thus, our sample is dominated by firms in the Chemical and allied products categories.

The empirical specification of the model differs somewhat from (6). The user costs of labor and research and development efforts have been omitted due to lack of appropriate data. The real wage rates for the appropriate two-digit industries are used as a proxy for these two user-cost variables. The user cost of capital for each firm is approximated by a measure constructed for the total manufacturing sector.[7] The output prices are not available at the firm level; therefore, we have used appro-

7. See the appendix for the specific formulation and source of data to generate this variable.

priate wholesale price indices of the two-digit manufacturing industries as the deflators for output, nominal wage rate, and the user cost of capital.

The proper concept for the research and development is the services of a given stock of R and D to the production of current output. Reliable estimates of the benchmark and depreciation rates for R and D at the individual firm level are not available. We constructed the stock of R and D by assuming an arbitrary depreciation rate of 10% per annum for each firm. The 1965 R and D investment in constant dollars is used as the benchmark for those firms that did not report any figures prior to 1965, while for firms with more extended data, the first year of consistent reporting was chosen as the benchmark.[8] Capital stock series for R and D and plant and equipment for each firm were constructed by the recursive formula,

$$K_{it} = I_{it} + (1 - \delta_i)K_{it-1}, \quad (i = 1, \ldots, 62), \tag{7}$$

where I_{it} is the deflated individual firm expenditure on R and D or new plant and equipment; the deflator used for converting nominal expenditure on R and D and plant and equipment into constant dollars is the deflator for plant and equipment (1958 = 100). The δ_i are the individual firm depreciation rates calculated for plant or equipment as the ratio of depreciation expenses to the benchmark capital stock obtained from the firm's balance sheet. As noted earlier, the depreciation rates for R and D are assumed to be fixed at 10%. The employment data refer to total employment of each firm. Unfortunately, it is not possible to break this aggregate series into production and nonproduction or scientists and engineers, etc. Similarly, it is not possible to separate the research and development expenditure into privately and publicly financed categories.

The specific estimating equations used are

$$\begin{aligned}
L_t &= \alpha_0 + \alpha_1 Q_t + \alpha_2 (w/c)_t + \alpha_3 L_{t-1} + \alpha_4 R_{t-1} \\
&\quad + \alpha_5 K_{t-1} + \alpha_6 U_{t-1} + \epsilon_1, \\
R_t &= \beta_0 + \beta_1 Q_t + \beta_2 (w/c)_t + \beta_3 L_{t-1} + \beta_4 R_{t-1} \\
&\quad + \beta_5 K_{t-1} + \beta_6 U_{t-1} + \epsilon_2, \\
K_t &= \gamma_0 + \gamma_1 Q_t + \gamma_2 (w/c)_t + \gamma_3 L_{t-1} + \gamma_4 R_{t-1} \\
&\quad + \gamma_5 K_{t-1} + \gamma_6 U_{t-1} + \epsilon_3, \\
U_t &= \delta_0 + \delta_1 Q_t + \delta_2 (w/c)_t + \delta_3 L_{t-1} + \delta_4 R_{t-1} \\
&\quad + \delta_5 K_{t-1} + \delta_6 U_{t-1} + \epsilon_4,
\end{aligned} \tag{8}$$

8. The regressions were also run with the flow measure of R and D expenditure. The overall results were generally similar to those reported in table 7.1.

where all the variables are in logarithms; R_t is the measure of research and development expenditures; L_t and K_t are the levels of employment and capital stock of the firm; Q_t is the level of output; (w_t/c_t) is the ratio of nominal wage rate and the user cost of capital goods. U_t is the rate of utilization of the appropriate two-digit industries used as a proxy for firms' utilization rate, R_{t-1}, L_{t-1}, and K_{t-1} are the lagged dependent variables, and ϵ_1, ϵ_2, ϵ_3, and ϵ_4 are the error terms.[9]

The adjustment processes are embedded in the coefficients of the lagged dependent variables. The own adjustment coefficient in each equation can be obtained from the regression coefficient associated with the lagged dependent variable, while the cross-adjustment coefficients are from the regression coefficients related to the lagged values of other dependent variables. For example, in the first equation of (8), the own adjustment coefficient is $\hat{\beta}_{11} = (1 - \hat{\alpha}_3)$ and the cross-adjustment effects of disequilibria in R and D and plant and equipment on employment are measured by $-\beta_{12} = \alpha_4$ and $-\beta_{13} = \alpha_5$. The matrix

$$B = \begin{bmatrix} \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 \\ \beta_3 & \beta_4 & \beta_5 & \beta_6 \\ \gamma_3 & \gamma_4 & \gamma_5 & \gamma_6 \\ \delta_3 & \delta_4 & \delta_5 & \delta_6 \end{bmatrix}$$

constitutes the 4×4 nondiagonal adjustment matrix which traces the interdependence of the adjustment paths of the three inputs and the utilization rate over time.

Before estimating these equations, the problem of heteroscedasticity in our sample had to be considered. Except for the three aggregate industry-wide variables w_t, $\dot{c}_t$, and U_t, the remaining variables in (8) are specific to each firm. Error variances for large firms will substantially exceed those of small firms and therefore the possibility that the cross-section within-cell regression functions will have unequal error variances will exist. As is well known, there are two ways to handle this possibility; the first is to test for the existence of heteroscedasticity among firms and eliminate the statistically significant outliers. The second approach is to transform variables so that the error variances will be homogenous (Kuh 1963). We have followed the second alternative. Two possibilities exist: (1) log transformation of the variables which equalizes the error variances on the assumption that they are strictly proportional to the size of the independent variables; (2) fitting the model in ratio form, which means dividing the firm-specific variables by an appropriate scale variable such as the total assets of the firm. Though we have used both of these procedures (using total deflated

9. See the appendix for definition, sources, and construction of the regression variables.

assets of the firms as the denominator in the ratio form of the model), we shall report only the logarithmic results.

Another important estimation problem that arises immediately is whether or not to impose the implicit constraint on the adjustment coefficients of model (8). If the adjustment coefficients are unconstrained, one of two hypotheses about the production function is implied: (1) if the production function constraint always holds as an equality, then the adjustment process implies that output is endogenous during the adjustment period; (2) on the other hand, if output is taken as exogenous, independent adjustments imply that firms may not be on their production functions. The values of the adjustment coefficients, then, will determine whether the firms are inside or outside of their production surface.

We have not imposed the necessary constraints on the adjustment coefficients, mainly because of the unreliability of the underlying data. Instead, we have assumed that output is endogeneous and have examined the unconstrained estimates of the adjustment coefficients to see whether the constraints implied by the model are met. The structural equation for each input is estimated by two-stage least-squares and the characteristic roots of matrix B are examined to check whether the implicit constraints are reasonably met.

7.4 The Structural Estimates

The model is estimated using the variance components technique for pooling cross-section and time series data developed by G. S. Maddala (1971). This method allows estimating the cross-section and time series effects separately and generates generalized least-squares estimates of the parameters of the model.[10]

The model (8) is estimated using the overall sample of sixty-two firms and three subsamples: twenty-eight firms with total assets below $300 million, twenty firms with assets greater than $300 million but smaller than one billion dollars, and fourteen firms of over one billion dollars in total assets. The estimation of the model using the stratified samples should provide a test of its stability and insight into whether firms of different sizes differ in their input decisions. We have also estimated both the ratio and logarithmic forms of (8) for all four samples. Only the generalized least-squares estimates of the model in logarithmic form are presented here.

10. The computer program based on this technique generates four regressions: the ordinary least squares (OLS), generalized least squares (GLS) without taking effect of cross-section and time effects, the least squares plus dummy variables (LSDV), which takes account of these effects, and finally the generalized least squares with dummy variables.

7.4.1 The Structural Estimates: The Overall Sample

The results in table 7.1 are the generalized least-squares estimates with cross-section and time dummies. Note that Q_t is the estimated value of the output variable Q_t.

The results indicate a consistent picture: the coefficients generally are statistically significant in both the OLS and GLS versions, the results of the ratio and logarithmic forms of the model were fairly similar, and the signs of the coefficients of all the variables except a few remained stable in the various versions of the model.

As can be seen from table 7.1, the statistical goodness of fit of the model measured by R^2 and sum of squared residuals (SSR) and estimated variance of errors (EEV) are very good. A separate test using the TSP regression program indicated that the Durbin-Watson test values were about 2.0 for each of the equations. However, this test is not only biased when a lagged dependent variable is included as an explanatory

Table 7.1 **Generalized Least-Squares Estimates of the Model in Logarithmic Form, Period 1965–72**

Independent Variables	Generalized Least-Squares Equations			
	Log L_t	Log R_t	Log K_t	Log U_t
Constant	−.3458	.6793	−.3035	−.2013
	(−.5135)	(1.889)	(−.8140)	(−2.077)
Log Q	.3355	.1970	.2279	.0290
	(5.482)	(7.614)	(5.758)	(2.933)
Log $(w/c)_t$	−.1742	−.2418	.0254	.0300
	(−1.6855)	(−1.876)	(.1773)	(.8151)
Log L_{t-1}	.5173	−.0904	−.0353	−.0253
	(8.507)	(−3.422)	(−.9482)	(−2.745)
Log R_{t-1}	.0997	.6999	−.0046	.0074
	(2.75)	(42.40)	(−.2094)	(1.34)
Log K_{t-1}	—.0544	.0804	.8175	−.0099
	(−1.62)	(5.391)	(40.33)	(−1.95)
Log U_{t-1}	−.3859	−.1772	−.4388	.6504
	(−2.220)	(−2.52)	(−3.565)	(20.42)
R^2	.9283	.9767	.9878	.8851
SSR	.3469	.3531	.3475	.3353
Degrees of freedom	365	365	365	365
EEV	.0105	.0017	.0054	.00033

NOTE: Abbreviations are explained in the text.

variable, but also may not be invariant with respect to the ordering of the firm data in our sample.

The estimates in table 7.1 indicate the immediate responses of the inputs to changes in output, relative input prices, their own lags, and cross-adjustment effects of other inputs. The coefficient of output is positive and statistically significant in each equation. The output elasticities indicate that changes in output have the strongest effect on employment (.34), followed by stocks of capital goods and research and development. The output elasticity of the utilization rate, U, which should be very high, is rather small. The explanation for this is that our measure of the utilization rate is an industry measure which may not respond greatly to movements of demand of the individual firms. The relative price variable is also statistically significant and negative in both research and development and employment equations; it has the correct positive sign but is not statistically significant in the capital stock equation or in the utilization equation.

The own lag coefficients of the three stock variables indicate that employment adjusts very rapidly ($1 - .52 = .48$), followed by stock of research and development expenditures, ($1 - .70 = .30$), while capital stock adjusts very slowly ($1 - .82 = .18$). These patterns of adjustment are consistent with our a priori notion and previous results. They suggest, if we ignore the spill-over effects, an average lag of a year for employment, two and one-half years for research and development, and about four years for the capital stock.[11] The adjustment coefficient for the utilization rate is unexpectedly long. Again, part of the reason is that U is an industry measure and cannot be explained readily by movements of firm data. There are significant cross-adjustment effects in each demand equation, though of varying magnitudes. These are calculated as $-\hat{\beta}_{ij}$, $i \neq j$—that is, the negative of the cross-adjustment coefficients shown in table 7.1. For example, $-\hat{\beta}_{ij}$, $j = 2,3,4$ measures the effects of excess demand in employment on stocks of research and development and capital and the utilization rate; they are shown by the coefficients in row L_{t-1} in table 7.1. The signs and magnitudes of the cross-adjustment coefficients vary among the equations, indicating an asymmetrical and varying disequilibrium effect. As noted, the direction of these effects will be the opposite of the signs of the coefficients shown in table 7.1.

1. Employment disequilibrium has strong positive effects on the utilization rate and stock of research and development expenditure. It also affects demand for capital goods positively, but the effect is not statistically significant. Thus, excess demand for labor increases the utilization rate and demand for plant and equipment and research development.

11. These calculations are only very tentative, for the adjustment patterns are interdependent and they cannot be ignored.

2. Excess demand in stocks of research and development has a strong negative effect on demand for labor; its impact on capital stock is positive but not very significant; its effect on the utilization rate, though positive, is barely significant statistically. Thus, disequilibrium in R and D capital reduces demand for labor but increases that of physical capital, implying a complementary relation with labor and a substitutional relation with physical capital.

3. Disequilibrium in physical capital has statistically significant positive effects on demand for labor and the utilization rate while it has a strong negative and statistically significant impact on demand for research and development expenditures. These patterns of response suggest a short-run complementary relation between stocks of capital goods and research and development and a substitutional relation with employment.

4. The cross effect of the rate of utilization on the demand for employment, research and development, and capital goods is positive and statistically significant in all cases. That is, disequilibrium in the utilization rate leads to increased demand for productive inputs.

5. These disequilibrium effects suggest that a firm faces excess demand in one of its inputs by increasing its rate of utilization and adjusting its demand for other two inputs. Thus, strong feedbacks and dynamical relations exist among the inputs in the short run.

From these results we conclude that there are strong and statistically significant short-term effects of changes in output and input prices on research development, employment, and investment demand of the firm. Also, there are some lags in achieving the desired levels of these inputs. The lags arise not only because of factors generating disequilibria in the specific input's own market but also because of disequilibria in other inputs as well. Dynamic feedback or spill-over effects among the three inputs do exist, and they tend to be asymmetrical in character. The utilization rate serves as a buffer allowing the firm to change its stocks of input. That is, when current demand increases, firms utilize their existing stocks of inputs first and then, if the demand is perceived as more permanent, they will adjust their stocks of inputs.

7.4.2 Structural Estimates for the Subsamples

The results in table 7.1 are essentially repeated when the model is fitted to the three subsamples mentioned earlier. The structural estimates for the subsamples are presented in table 7.2. The striking overall conclusion that emerges from a comparison of the results in tables 7.1 and 7.2 is the stability of the model in terms of signs and significance of the coefficients, and the goodness-of-fit statistics such as R^2 and sum-of-squares errors. The magnitudes and statistical significance of the coefficients vary somewhat across different asset sizes. The output vari-

Table 7.2 **Generalized Last-Squares Estimates of the Model in Logarithmic Form for Three Samples of Firms, Period 1965–72**

Independent Variables	Twenty-Eight Small Firms Equations				Twenty Medium-Sized Firms Equations				Fourteen Large Firms Equations			
	Log L_t	Log R_t	Log K_t	Log U_t	Log L_t	Log R_t	Log K_t	Log U_t	Log L_t	Log R_t	Log K_t	Log U_t
Constant	− .0175 (− .0198)	.8677 (1.888)	− .4155 (− .7361)	− .1795 (−1.518)	−3.4175 (−2.031)	.1419 (.4093)	.3517 (.5351)	− .3415 (−1.432)	.6690 (.4639)	.0917 (.1921)	.7089 (1.059)	− .0591 (− .1638)
Log Q_t	.1828 (2.003)	.2093 (5.755)	.2459 (3.408)	.0231 (1.725)	.5640 (5.274)	.1072 (2.424)	.1977 (3.821)	.0341 (1.745)	.9619 (5.692)	.0913 (1.9345)	.2290 (3.7395)	.0428 (1.1480)
Log $(w/c)_t$	− .1410 (− .4254)	− .3216 (−1.975)	.0615 (.2779)	.0319 (.6954)	.6427 (1.187)	− .0057 (− .0396)	− .0190 (− .0821)	.0797 (.9506)	− .6367 (−1.285)	.0718 (.4457)	− .0990 (− .4410)	.0024 (.0185)
Log L_{t-1}	.6587 (7.309)	− .1394 (−3.7)	− .0324 (− .4831)	− .0175 (−1.3793)	.1329 (1.015)	.0038 (.0832)	− .0342 (− .5525	− .0331 (−1.571)	.1581 (1.417)	−.0241 (−.7772)	− .0589 (−1.4703)	− .0333 (−1.3625)
Log R_t	.1028 (2.1625)	.6569 (32.981)	− .0164 (− .472)	.0042 (.6090)	.4347 (3.7784)	.9365 (35.532)	.0768 (1.605)	.0157 (1.1005)	− .0386 (− .4965)	.7835 (34.787)	−.0101 (− .3428)	.0141 (.7913)
Log K_{t-1}	− .0649 (−1.516)	.1079 (6.2154)	.7994 (24.609)	− .0114 (−1.8116)	− .2485 (−1.2013)	− .0801 (−2.831)	.6827 (15.182)	− .0185 (−1.1888)	− .3430 (−3.0043)	.0596 (1.6578)	.7417 (15.172)	− .0350 (−1.4667)
Log U_{t-1}	− .3049 (−1.0693)	− .1769 (−1.683)	− .5847 (−2.466)	.6607 (13.85)	− .3088 (−1.2013)	− .1775 (−1.481)	− .1429 (−1.1042)	.6272 (10.988)	−1.3089 (−3.922)	−.2421 (−2.534)	− .4469 (−3.546)	.6265 (8.3232)
R^2	.9648	.9923	.9897	.9443	.9632	.9968	.9835	.9668	.7802	.9798	.9515	.7675
SSR	.1562	.1608	.1568	.1537	.1099	.1062	.1079	.1037	.07604	.07927	.07672	.07610
Degrees of freedom	161	161	161	161	113	113	113	113	77	77	77	77
EEV	.0134	.0018	.0105	.0003	.0052	.0014	.0013	.0002	.0078	.0006	.0009	.0004

able is statistically significant in all of the regressions; the magnitudes of the coefficients are larger and similar to that of the overall sample for the firms with assets greater than one billion and those with assets less than 300 million dollars. For the "medium" size firms the short-term responses of the inputs to changes in output, except in the employment equation, is somewhat smaller. The relative price variable (w/c) has the correct sign in most cases, but in most of the regressions its magnitude and statistical significance varies. However, except in the employment equations, the coefficients of the relative price variable are statistically insignificant.

The own and cross-adjustment coefficients are quite strong in some of the regression equations in table 7.2. The asymmetrical pattern noted for the whole sample holds in the subsample regressions as well; the magnitudes of the own and cross-adjustment coefficients, however, vary among firms with different asset sizes. The weakest links in the feedback among the input disequilibria are observed in the effects of excess demand for R and D of firms with assets over one billion dollars. Disequilibrium in capital stock has strong effects on the demand for research and development of firms in all asset categories. The utilization rate positively affects the demand for all the inputs as we noted earlier for the whole sample of firms. The employment disequilibrium has a fairly weak effect on demand for R and D and capital stock in the medium-size and large firms.

Though these differences in individual coefficients may exist, still the overall significance of these differences may not be very significant. To test the stability of the model across the asset classifications, we computed the relevant F statistics for each set of input demand equations,

$$F = \frac{\mathrm{SSR_T} - (\mathrm{SSR_{14}} + \mathrm{SSR_{20}} + \mathrm{SSR_{28}})/k}{(\mathrm{SSR_{14}} + \mathrm{SSR_{20}} + \mathrm{SSR_{28}})/N-3k}$$

where SSR_T is the sum-of-squared residuals from the regression for the 62 firms and SSR_{14}, SSR_{20}, SSR_{28} are the sum-of-squared residuals from the regressions for the subsamples of firms. N is the overall number of observations and k is the number of the parameters estimated. The calculated F statistics for L, R, and K equations are 0.689, 0.9504, 0.8927 and 0.2652, respectively, and the critical value of $F(7,344)$ at the 1% level is 2.69. Therefore, the null hypothesis of an unchanging structure of demand functions for labor, research and development, and capital goods cannot be rejected.

The Cross Section and Overtime Differences among Firms

The analysis of variance employed in estimating the demand equations permits testing whether cross-section and time series differences exist among our sample of firms in their input decisions. We have calculated the F statistics based on the estimates generated by the least-squares plus dummy variables (LSDV) of the analysis of variance. The results in table 7.3 pertain to the logarithmic form of the model using the entire sample and the three subsamples of firms. They indicate an interesting pattern: substantial cross-sectional differences exist among firms with respect to *all* of the inputs and, except for the demand for research and development expenditure in the small and medium-size firms, all the input functions also vary over the span of time considered.

It is difficult to precisely state the causes of the cross-sectional and time series differences among the samples of firms in their input decisions. The cross-sectional difference may arise from the differences in the characteristics of firms such as being in different industries, producing different types of products, having different degrees of monopoly or monopsony in the markets, etc. The overtime differences may be due to differing adjustment processes, responses to external shocks, and technological changes. Though very desirable, a closer look into the

Table 7.3 Values of F-Statistics from Analysis of Variance for the Entire Sample and Three Subsamples of Firms, Period 1965–72

		Effects	
Group	Dependent Variable	Cross Section	Time-Series
Overall sample: sixty-two firms	L_t	63.5776	5.2096
	R_t	245.087	10.3005
	K_t	21.6712	7.6988
	U_t	19.5848	173.861
Fourteen large firms	L_t	81.5190	3.5241
	R_t	161.635	9.2359
	K_t	204.780	18.0309
	U_t	45.4924	31.5152
Twenty medium-sized firms	L_t	481.675	62.9452
	R_t	38.3298	1.1649
	K_t	267.811	9.7051
	U_t	47.5290	90.3784
Twenty-eight small firms	L_t	357.410	41.1140
	R_t	321.932	3.6381
	K_t	14.5643	2.5744
	U_t	16.1273	90.8643

NOTE: The critical values of F for the cross-section estimates at .05 are approximately as follows: $F(61,305) = 1.47$ for the entire sample, $F(13,65) = 2.42$ for the fourteen large firms, $F(19,95) = 2.09$ for the medium-sized firms, $F(27,135) = 1.85$ for the twenty-eight small firms. The critical values of F for the time series estimates at .05 are respectively $F(5,305) = 3.09$, $F(5,65) = 3.29$, $F(5,95) = 3.20$, and $F(5,135) = 3.17$.

sources of these differences in input demand functions of the firms is beyond the scope of our present research.

7.5 The Long-Run Elasticities of Inputs and Labor Productivities

From the structural estimates reported in tables 7.1 and 7.2, we can calculate the implied long-run output and price elasticities of the three inputs. Using these statistics, it is possible to obtain the long-run labor productivity estimates for the total number of firms and for the sample of firms classified by asset size. The long-run elasticities are identical to the coefficients of equation (5) (in log form) and are computed from the stationary solutions of the structural equations (8). Note that the long-run output elasticities of employment, research and development, and capital stock demand functions estimate the inverse of returns to scale, $1/\rho = 1/(\alpha_1 + \alpha_2 + \alpha_3)$.

Several features of these figures in table 7.4 should be noted:

1. The surprising similarity of the output elasticities among the inputs. Long-run elasticities of capital, however, tend to be somewhat larger in the overall sample and the sample of small firms.

Table 7.4 **Long-Run Output and Price Elasticities for the Overall Sample and Subsamples of Firms**

	Variables	
Sample Size	Output	Relative Prices
Sixty-two firms		
L	.7103	−.5954
R	.7142	−.6946
K	1.0521	.0029
U	.0172	.1143
Fourteen large firms		
L	.8495	−.7816
R	.5212	.1656
K	.6822	−.4230
U	−.0056	.1222
Twenty medium-sized firms		
L	.8365	−.6632
R	.7922	−.1836
K	.7179	−.2474
U	.0149	.1597
Twenty-eight small firms		
L	.5393	−.9202
R	.7105	.3758
K	1.0394	.3058
U	.0141	.0434

2. The output elasticities in the labor, research and development, and capital stock demand equations, except for the two cases noted, are less than unity, which implies in general a slightly increasing return to scale in the production process. The output elasticity of the utilization rate, as we expect, is approximately zero in the long run.

3. The elasticity of employment, stock of research and development, and capital stock with respect to relative input prices are generally larger for employment than for other inputs. The sign of the relative price is volatile for the stocks of research and development and capital goods. The relative price variable has a small but positive effect on the rate of utilization.

As we noted earlier, certain relationships among the adjustment coefficients, β_{ij}'s, are implied by the model. The relevant restriction we seek is for

$$\alpha(I - B) = 0,$$

where α is a vector of Cobb-Douglas exponents and B is the matrix of adjustment coefficients. Since each α_j is nonzero, then $|I - B| = 0$. In principle, this provides the test of the restrictions; otherwise the production function will be overidentified. One way to fulfill this test is to look for the characteristic roots of $|I - B|$ to have modules less than unity which would insure that $|I - B|$ will approach zero.

In table 7.5, the characteristics roots of $|I - B|$ for the entire sample of firms and its subcategories are listed. These roots are complex and less than unity in absolute values, suggesting that the response patterns of the inputs display damped oscillations and that the restriction of $|I - \hat{B}| = 0$ is approximately met.

7.5.1 Research and Development and Labor Productivity

To illustrate the influence of research and development expenditures on labor productivity we can perform certain conceptual experiments using the estimates shown in tables 7.1 and 7.2. We can generate short and long-run labor productivity indices depending on what factor of production we assume to be fixed. To obtain the short-run partial pro-

Table 7.5 **Characteristic Roots of |I−B| (calculated using estimates from tables 7.1 and 7.2)**

Entire Sample	14 Large Firms	20 Medium-Sized Firms	28 Small Firms
$.8293I \pm .3519i$	$.8023I \pm .0569i$	$.9201I \pm .1443i$	$.8242I \pm .2428i$
$.6857I \pm .1247i$	$.6728I \pm .5489i$	$.7241I \pm .1576i$	$.6838I \pm .6616i$
.4844	.0325	.1018	.5839

ductivity index, we consider the employment functions in these tables in isolation and assume that the levels of both research and development and capital stock of the firm are exogenously given and fixed in the short run. Thus, with our model (8) reduced into a single employment equation, we transform the employment functions in tables 7.1 and 7.2 into short-run productivity equations where labor productivity will be a function of output, relative input prices, previous levels of capital stock, employment, and research and development expenditures. From the magnitude of the output coefficient in the equation it is possible to infer whether employment moves proportionately with output in the short run. As indicated in table 7.6 the short-run coefficient of output in the productivity equation, $1/\alpha_q$, is positive and smaller than unity in each case except for the firms with total assets greater than one billion dollars. In other cases there is evidence of increasing return to labor in the very short run (Sims 1974). We also observe that the short-run impact of changes in research and development and capital stock varies considerably among the samples of firms. Research and development seem to exert the most significant effect on productivity in the case of large and medium-size firms, while the capital stock seems to have the largest positive effect on labor productivity in the case of the small firms followed by a fairly sizable effect on labor productivity of medium-sized firms.[12]

To determine the behavior of the labor productivity in the intermediate run, we shall assume that both employment and research and development investment are variable and only the capital stock of the firm is fixed. This reduces the estimating model to a two-equation interrelated model in employment and research and development expenditures. Solving the two-equation system, and after appropriate conver-

12. These results should be interpreted with caution since our classification of assets by size of total assets is rather arbitrary.

Table 7.6 **Short-Run Response of Labor Productivity to Changes in Output, Research and Development, and Capital Stock in the Overall Subsamples of Firms**

	62 Firms	14 Large Firms	20 Medium-Sized Firms	28 Small Firms
$(1 - 1/a_q)$	0.333	0.085	0.462	0.502
$R_t - 1$	0.256	0.162	0.165	0.398
$K_t - 1$	0.105	0.151	0.233	0.002

NOTE: These figures are based on estimates in tables 7.1 and 7.2 which are converted to elasticities.

sions, we obtain the intermediate elasticities of labor productivity with respect to output, $(w/c)_t$, R_{t-1}, and K_{t-1}. The effects of research and development on labor productivity is transmitted now through the embedded feedback process and is reflected in the coefficients of output and relative input prices. The results of this experiment indicate that the output elasticity of employment moves generally close to unity for each of the firms in the sample.

Finally, the long-run labor productivity is calculated when all the variables are changing. The magnitudes of output elasticity of labor are the same as those reported for employment in table 7.5. These figures suggest that long-run labor productivity is independent of the cyclical changes in output and the production process is probably subject to a slight degree of increasing returns to scale.

Comparison of these experiments indicates that the reason for the large returns to labor reported from the estimated short-run employment functions is the assumption of fixity of other inputs or input services. The high estimates reported in the literature should be interpreted not as a return to labor alone, but as a short-run return for all inputs. These experiments, however, are basically conjectural since our basic model stresses the dynamic interrelationships of all factors. All variables are specified as "quasi-fixed" and none of them are really entirely fixed in the short run. Yet the procedure suggests that labor productivity is affected by cyclical changes in output in the short run, while in the intermediate run this effect declines and in the long run it finally vanishes. Labor productivity is also significantly affected in the short run and also in the long run by the level of research and development activities.

7.6 Conclusions and Summary

The results presented in this paper indicate that the firm's employment, capital accumulation, and research and development decisions are closely intertwined, and a dynamic interaction process seems to underlie these decisions. The research and development activities of the firm, like its demand for labor and capital, are influenced significantly by changes in output and relative input prices. The long-run output elasticities of the inputs, especially those of labor and research and development, are quite similar and suggest a slight increasing return to scale in production. Both labor productivity and investment demand of the firms are significantly affected by their research and development expenditures. These results are in contrast to the findings of the familiar investment and employment functions which often have ignored the explicit role of research and development. We found that the demand for the three inputs are stable when firms are stratified by size of their assets; however, there is evidence of cross-sectional and overtime differences among firms in their input decisions. The causes of such differences are not explored at the present.

To improve our empirical results some of the shortcomings of our present data base have to be remedied. It would be useful to enlarge our sample of firms both in numbers and in their distribution among wider industry classifications. The wage rates and user cost of capital could be improved by obtaining more disaggregate measures of these variables; there is need for constructing the rental price of research and development activities and developing better capital stock measures for research and development at the firm level. It would be useful, if data permit, to classify the firms by industry classification and contrast the interindustry differences in employment, capital accumulation, and research and development expenditures. A test could also be developed to estimate the sensitivity of firms' demand for inputs to changes in aggregate economy variables and to examine more closely the cyclical characteristics of these input demand functions.

Improvement in these directions will be pursued in the near future. For the present, however, it is gratifying to note the methodological integration of research and development expenditure in a unified framework of input decisions of the firm, and the empirical evidence presented here to substantiate the presence of dynamic interaction of input demand functions at the micro level.

Statistical Appendix

The Data and Specification of the Variables

The sample of firms used in this study consists of sixty-two firms mainly from five industries: metal extraction, chemicals and allied products, nonelectrical machinery, electrical equipment and supplies, and instruments. The names and SIC classification of the firms are indicated in table 7.A.1; also indicated are the classifications of these firms by their 1970 asset size. The choice of the sample was somewhat arbitrary; firms with continuous data on research and development expenditures for the period 1965–72 were chosen from the Compustat tapes. Aside from individual firm data, we have compiled data on prices, wage rates, and utilization rates on a two-digit industry basis. Absence of these data at the micro level made use of the industry-level statistics imperative.

The construction of the variables used in model estimations are as follows:

Table 7.A.1 Companies Included in the Samples of Our Experiments

Standard Industrial Classification Number (1)	Names of Companies (2)	Companies Classified by Asset Size (1970): Below $300 (M) (3)	From $300 to $1000 (M) (4)	Over $1000 (M) (5)
1000	American Smelting & Refining		X	
1000	Brush Wellman Inc.	X		
1000	Cerro Corp.		X	
1000	Molybdenum of America	X		
1031	St. Joe Minerals Corp.	X		
2801	Allied Chemical			X
2801	American Cyanamid			X
2801	Celanese Corp.			X
2801	Grace (WR) & Co.			X
2801	Hercules Inc.		X	
2801	Monsanto Inc.			X
2801	Union Carbide			X
2802	Diamond Shamrock Corp.		X	
2802	Stauffer Chemical		X	
2803	Akzona		X	
2803	Cabot		X	
2835	Abbot Laboratories		X	
2835	Lilly Eil & Co.		X	
2835	Merck & Co.		X	
2835	Pfizer		X	
2835	Schering Plough		X	
2835	Smith-Kline	X		
2835	Syntex	X		
2835	Upjohn		X	
2835	Warner Lambert			X
2836	Bristol Meyers		X	
2836	Richardson-Merell Inc.		X	
2837	Baxter Laboratories	X		
2837	Becton Dickinson	X		
2844	Nestle Lemur	X		
2899	Ansul Co.	X		
2899	Diversey Corp.	X		
2899	Lubrizol Corp.	X		
3531	FMC Corp.			X
3550	Leesona	X		
3550	McNeil Corp.	X		
3570	Addressograph-Multigraph		X	
3570	Burroughs Corp.			X
3570	National Cash Register			X
3570	Pitney-Bowes Inc.		X	
3570	Xerox Corp.			X
3571	Potter Instrument Co.	X		

Table 7.A.1 (cont.)

Standard Industrial Classification Number (1)	Names of Companies (2)	Companies Classified by Asset Size (1970): Below $300 (M) (3)	From $300 to $1000 (M) (4)	Over $1000 (M) (5)
3573	Memorex Corp.	X		
3573	Systems Engineering Labs	X		
3579	Nashua Corporation	X		
3600	Sperry Rand Corp.			X
3610	Thomas & Betts Corp.	X		
3611	Bourns Inc.	X		
3622	Barnes Engineering	X		
3670	Raytheon Co.		X	
3670	Collins Radio Co.		X	
3679	Mallory (Pa) & Co.	X		
3679	Sprague Electric Co.	X		
3811	Beckman Instruments	X		
3822	Robert Shaw Controls	X		
3825	Hewlett-Packard Co.	X		
3825	Varian Assoc.	X		
3831	Bausch & Lomb Inc.	X		
3831	Perkin Elmer Corp.	X		
3861	Minnesota Mining & Manufacturing			X
3861	Eastman Kodak			X
Number of Companies:	62	28	20	14

$A_t =$ total assets of the firm taken from Compustat tapes deflated by the deflator for fixed investment series in *Survey of Current Business*, various issues.

$R =$ the stock of research and development expenditures of the individual firms. This variable was generated by the recursive formula

$$R_t = RD_t + (1 - \delta')R_{t-1},$$

where RD_t is the research and development expenditure of individual firms, and R_{t-1} is the previous stock of research and development expenditures; δ' is assumed to be .10 for each firm.

$L_t =$ number of company employees in thousands from Compustat tapes.

$K_t =$ individual capital stock of the firm generated using perpetual inventory method. The recursive formula to generate capital stock series for each firm is

$$K_{it} = I_{it} + (1 - \delta_i)K_{it-1}.$$

$\delta_i =$ the depreciation rate as calculated by (depreciation expenses)/gross plant given on each firm's balance sheet in the benchmark year. The benchmark capital stock K_t is the deflated value of net plant for most firms in 1953. The deflator is the general fixed investment price deflator (P_k). For some firms where data on net plants for 1953 were not available, we used the earliest available figures. Investment series were taken from each firm's balance sheets and deflated by P_k.

$Q_t =$ the output variable defined as

$$S/P + [I/P - (I_{t-1}/P_{t-1})];$$

S is the net sales for individual firms, obtained from Compustat tapes, and P is the wholesale price index for the relevant two-digit industry reported in various issues of *SCB*. I refers to inventories of individual firms; its values were obtained from Compustat tapes.

$w_t =$ average hourly earnings of production workers of relevant two-digit industries taken from *BLS, U.S. Employment and Earnings, 1909–1971*, and *Monthly Labor Statistics, 1972 and 1973*. These figures were deflated by the corresponding wholesale price index given in various issues of *Survey of Current Business*.

$c_t =$ the user cost of capital divided by the relevant wholesale price index at the two-digit industry level. It was assumed that the nominal value of the user cost of capital is the same for each firm within and across industries. The user cost variable was generated as follows:

$$c = \frac{P_k(r + \delta)(1 - \bar{k} - zv + zk'v)}{(1 - v)},$$

where P_k is the price of investment goods, the data of which are the implicit GNP price deflator for fixed investment series in the *Survey of Current Business*; r is the *real* rate of interest, defined as $r = i - (\dot{P}/P)^e$, where i is the discount rate, the data of which are the nominal quarterly interest rates on Moody's Aaa Bonds, and $(\dot{P}/P)^e$ is the expected inflation rate calculated as the weighted average of changes in the implicit GNP price deflator for fixed investment series, with weights taken from Robert J. Gordon, "Inflation in Recession and Recovery," *Brookings Papers on Economic Activity* 1 (1971):148; $\bar{k}$ is the effective rate of quarterly investment credit, set to be .055 per quarter following Charles W. Bischoff, *Brookings Papers on Economic Activity*, 3(1971):735–753; k' is the tax credit allowance under the Long Amendment that required firms to subtract their total tax credit from the depreciation base, the value of k' being equal to that of $\bar{k}$ (.055) when the Amendment was in force and equal to zero for other time periods; v is the corporate income tax rate; and z is the present value of the depreciation deduction, the data of which have been constructed according to Nadiri, "An Alternative Model of Business Investment Spending," *Brookings Paper on Economic Activity* 3(1972):576.

$U_t =$ the Wharton index of utilization rate for the five two-digit industries.

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Comment Richard C. Levin

Nadiri and Bitros provide an interesting new approach to the analysis of research and development and productivity growth at the firm level. There exists a considerable literature on the determinants of R and D expenditures, with particular emphasis on firm size and industry characteristics such as concentration and technological opportunities. Several studies, including the Griliches and Terleckyj pieces in this volume, have

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focused on measuring the long-run returns to R and D. We also have bodies of literature concerned with the diffusion of innovations, the effects of uncertainty on research strategies, and the role of public policy in the area of R and D. Nowhere to my knowledge, however, has there been an explicit focus upon the short-run disequilibrium dynamics of R and D expenditure, embedded in a general dynamic model of input and D expenditures using an arbitrarily assumed 10% annual depreciation rate.

Nadiri and Bitros put forth a model of input demand which permits them to analyze a variety of issues:

1. They examine the short-run effects of changes in output and relative factor prices on the demand for capital, labor, and R and D activities.
2. They estimate the effects of excess demand for each of the inputs on the demand for other inputs.
3. By stratifying their sample of firms by asset sizes they are able to test whether firm size affects the pattern of input demands and dynamic interactions. In this way Nadiri and Bitros touch base with the literature on the relationship between firm size and innovative activity.
4. Finally, the authors derive from the estimated parameters of their model the effects of R and D on labor productivity in the short, intermediate, and long runs.

The dynamic model introduced in this paper is an extension of Professor Nadiri's earlier work on disequilibrium models of factor demand (Nadiri and Rosen 1973). The present paper is an extension in the sense that R and D is included as a factor of production, but it is a simplification of the earlier work of Nadiri and Rosen insofar as only stocks of inputs and the utilization rate of capital are incorporated into the production function, and not the utilization rates for each factor. Essentially, the model is a generalization of the familiar partial adjustment approach to modeling disequilibrium:

$$Y_{1t} - Y_{1t-1} = \beta(Y^*_1 - Y_{1t-1}), \tag{1}$$

where Y^*_1 is the desired level of factor Y_1 and β the adjustment coefficient.

Nadiri and Bitros generalize this model so that each period's change in the demand for a single input reflects the deviation of actual from desired stocks for all the inputs. Thus, for the two-input case,

$$\begin{aligned} Y_{1t} - Y_{1t-1} &= \beta_{11}(Y^*_1 - Y_{1t-1}) \\ &\quad + \beta_{12}(Y^*_2 - Y_{2t-1}). \\ Y_{2t} - Y_{2t-1} &= \beta_{21}(Y^*_1 - Y_{1t-1}) \\ &\quad + \beta_{22}(Y^*_2 - Y_{2t-1}), \end{aligned} \tag{2}$$

If the values of the adjustment coefficients are unconstrained, one of two additional hypotheses is needed to close the model: (1) firms may be assumed to remain on the production function during the adjustment period, in which case it is implied that output is endogenous; (2) alternatively, if output is assumed to be exogenous, independent input adjustments imply that firms need not be on the production function. Indeed, firms may be inside or outside of the production surface, depending on the values of the β's.

The first hypothesis seems appealing: that disequilibrium in factor markets implies that firms fail to produce along their optimal expansion paths. It seems quite reasonable to assume that output decisions are constrained by input disequilibria. Nadiri and Bitros note that there is a third alternative which permits output to remain exogenous *and* firms to be on the production function. This approach implies severe restrictions on the adjustment coefficients. To illustrate, if output is exogenous a firm will move from output X_1 to X_2 in a certain time period (see fig. 7.C.1). If the production function constraint holds as an equality, then the firm must use a combination of inputs on the isoquant X_2. If the desired input combination is at point B, excess demand in the market for one factor will necessarily imply overshooting the target level of the other factor. In a model with several factors of production, at least one must overshoot its target level to compensate for excess demand elsewhere.

This implied hypothesis of overshooting target values of one or more inputs had considerably more intuitive appeal in the earlier work of Nadiri and Rosen than it does here. In Nadiri and Rosen (1973), utilization rates of each input entered directly (if perhaps too independently) into the production function. It seems quite reasonable to assume that excess demand for capital or labor would lead to an overshooting of target values of utilization rates, but it is not quite so obvious that stocks would overshoot in the same way. In the present paper, only the utilization rate of capital enters into the production function.

Nadiri and Bitros complete the model by substituting for the Y^* terms in the adjustment equations an approximation to the factor demand functions derived from a Cobb-Douglas production function. Embedded in the coefficients of the resulting system of equations are the estimated values of the adjustment coefficients, and the elasticities of each input with respect to factor prices and output.

The model is estimated on pooled cross-section and time series data on 62 firms for the period 1965–72. The limitations of the data are, as usual, serious. Wage rates at the two-digit industry level are used to represent the user cost of both labor *and* R and D. The utilization rate is also an industry figure, rather than firm-specific. The output variable was constructed by deflating firm revenues by the wholesale price index

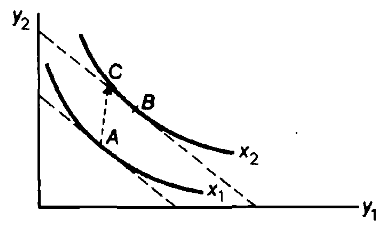

Fig. 7.C.1 Interactions among Time Paths of Inputs

of the appropriate two-digit industry. Total employment is used for the labor stock variable, which implies that R and D employees are counted twice. The R and D stock variable is constructed from cumulative R and D expenditures using an arbitrarily assumed 10% of annual depreciation rate.

Despite the limitations of the data, Nadiri and Bitros obtain a remarkably good fit of their model with generalized least-squares estimation. I shall briefly summarize the results, quibbling with a few of their interpretations along the way, before I conclude by expressing some more fundamental worries about their overall approach.

1. Nadiri and Bitros find that all inputs respond significantly to short-run changes in output—the output elasticity of labor being highest, that of R and D lowest, and that of capital in between. Employment and R and D respond significantly to short-run changes in relative factor prices, but not capital or the utilization rate. This pattern of responsiveness to factor prices in the short run is inconclusive, given the poor quality of the price data.

2. The own adjustment coefficients are all statistically significant and have the correct signs; the magnitudes suggest that employment adjusts most rapidly, followed by R and D and capital. The utilization rate adjusts more slowly than expected, but this is doubtless a consequence of using an industry-wide measure of utilization instead of a firm-specific measure.

3. When the sample is stratified by asset size into three groups, Nadiri and Bitros are able to reject the null hypothesis of an unchanging structure of input demands. Thus we have one more piece of evidence to add to the endless debate on the so-called Schumpeterian hypothesis—which we all know by now is not really a Schumpeterian hypothesis—namely, that large firms do more R and D.

4. In the final section Nadiri and Bitros calculate the long-run output elasticities of the inputs from the coefficients of their estimated equations. These results are presented in a most confusing manner, since the authors do not report the output elasticity of each input separately, but

rather they report the *sum* of the elasticities of the inputs for each of the equations. These results suggest constant or increasing returns to scale. It would be useful to have separate calculations of the output elasticity of each input.

5. Finally, the authors calculate what they interpret as the short, intermediate, and long-run responses of labor productivity by varying in turn labor alone, then labor and R and D, and finally all factors. The meaning of this conceptual experiment is not entirely clear within the context of their model, which after all requires that all inputs must vary in the short and intermediate runs. It would seem instead that if the authors were interested in the returns to R and D they would examine the long-run elasticity of output with respect to R and D, which is a way of capturing how changes in R and D affect the productivity of the conventional inputs. This elasticity can be converted, with the appropriate caveats mentioned by Professor Griliches in his paper, into a kind of crude average rate of return on R and D.

I would like to close with a more fundamental criticism of the paper. I have some difficulty in grasping the connection between the model proposed by Nadiri and Bitros and the estimation techniques they employ. In the version of the paper presented at the conference, the authors held to the pair of assumptions noted above: that firms are on the production function and that output is exogenous. They failed, however, to impose the appropriate restrictions on the β_{ij}, the own and cross-adjustment coefficients. In an effort to remedy this deficiency, the authors have chosen to leave the adjustment coefficients unconstrained and to treat output as endogenous. But merely asserting that output is endogenous and running two-stage least-squares does not get them out of the woods. Several problems remain:

1. If output is assumed to be endogenous, the behavioral assumption of cost minimization given output is no longer appropriate. Presumably, this assumption would be replaced by profit maximization subject to the production function constraint, but this will introduce product price as an exogenous variable.

2. If output is endogenous and product price enters the model, it is not obvious without further argument that the inferences made from the estimates about the parameters of the production function and the adjustment equations will hold.

3. Since the estimated equations are neither the structural nor the reduced form, it is not clear that the error terms are appropriately specified. If stochastic terms enter the structural equations in a simple linear or multiplicative fashion, they will not enter linearly and independently in the equations estimated.

4. Even if the appropriate reduced-form equations were derived, the assumption that firms are on the production function suggests that the

error terms will not be independent across equations. Joint estimation imposing the appropriate restrictions would still be warranted.

While these problems are serious, they are in principle remediable. Despite these objections, this is a very interesting paper and an important further step toward building disequilibrium dynamics into the theory of the firm. I hope the authors will further pursue this line of inquiry, with a richer data base if possible, using a more fully specified model and appropriate joint estimation techniques.

Reference

Nadiri, M. Ishaq, and Rosen, Sherwin. 1973. *A disequilibrium model of demand for factors of production.* New York: National Bureau of Economic Research.