Indian Economic Review, Vol. XXIII, No. 2

R & D Behaviour of Indian Firms : A Stochastic Control Model

L. K. RAUT†
University of California-San Diego, La Jolla, CA 92093

ABSTRACT

This paper develops a dynamic stochastic model to explain the observed pattern of R & D input choices of Indian private firms in terms of firm size, market structure, and science base. The inputs to the production of technological knowledge are taken to be in-house R&D activities, and purchase of technology and know-how from foreign and domestic suppliers. The model is estimated with firm level data from light, petro-chemical, and heavy industries. In all three industries larger firms tend to substitute domestic for foreign purchase of technology and technical know-how; and in heavy industry, larger firms also do more in-house R&D. Monopoly power of a firm in the light industry has no significant effect on its R&D activities; in the heavy industry, higher monopoly power to a firm reduces its purchase of technology without affecting other R&D activities; in the petro-chemical industry, higher monopoly power to a firm reduces its purchase of technology, but this reduction is partially offset by an increase in in-house R&D expenditures.

1. INTRODUCTION

In the post-Marxian literature Schumpeter (1934, 1950) was the first to envision technological change in a capitalist system as a race of "creative destruction" among firms. He observed that in a market economy investment in technological innovation is like any other economic activity, and argued that (1) the rate of innovation and monopoly power of a firm are positively related, and (2) the rate of innovation rises more

†This paper is drawn from my Ph. D. dissertation at Yale University in 1985. Carl Dahlman, Zvi Eckstein, Robert Evenson, T. N. Srinivasan and Lien Tran gave many comments. I also benefited from participants of seminars at Yale University, and George Washington University and an anonymous referee of the *Indian Economic Review*. I am, however, responsible for the remaining errors.

than proportionately with the size of the firm. These are known in the literature as the Schumpeterian hypotheses. In a seminal paper, Solow (1957) found that a major source of growth in U.S. labour productivity did not come from growth in inputs but from technological change. Denison later (1962) refined Solow's calculations and came to the same conclusion. These findings spurred many theoretical and empirical studies on research and development expenditures at the firm level in developed countries (see Griliches (1984), and Kamien and Schwartz (1981), Raut (1985) and Scherer (1980, Chap. 15) for references).

The main developments in the theoretical literature have been in the modelling of the Schumpeterian hypotheses in decision theoretic and game theoretic framework (see Kamien and Schwartz (1981). Other hypotheses have been formulated in terms of demand pull, supply push and optimal searching Schmookler (19 6) argued that market demand for goods induces innovation—this is known as the demand pull hypothesis. Rosenberg (1976) and Scherer (1986) emphasized that changes in engineering and scientific knowledge base of an industry make new products or processes feasible and thus affect its firms' R & D activities—this is known as technology-push hypothesis. More recently, using simulation analysis, Nelson (1982), Nelson and Winter (1978) have extensively studied the nature, sources, and the role of technological knowledge in innovation activity, and R & D decision making.

Empirical studies at the firm level have mainly been concerned with the testing of Schumpeterian hypotheses and the effect of R & D expenditures on productivity growth (for references, see Kamien and Schwartz (1981), and Griliches (1984). Measurement of an increment in technological knowledge has remained a great problem for empirical studies of technological change. In a series of NBER studies (reported in Griliches (1984), several attempts have been made to use the U.S. firm level data for investigating how the output of in-house R & D efforts, i.e., technological knowledge, could best be measured by such firm characteristics at the number of patents applied for, the increase in value of its stock, and increase in overall productivity. In these studies the performance of stock prices is not satisfactory; but the productivity gains and the number of patent applications do seem to measure increments in knowledge quite satisfactorily. Lall (1982), Lall and Mohammad (1983) take technology exports as another measure of advancement in technological knowledge, although, like stock market valuation, such an indicator may not always reflect an increment in knowledge.

A common shortcoming of these models is their view of in-house R&D effort as the only source of technological innovation. Moreover, these models generally assume that innovations are "big jumps" in the frontier of technology (sometimes called "Schumpeterian syndrome"). While these models, to a certain extent, reflect the process of technological change of firms in DCs, they need to be extended to take into account other sources of technological knowledge for the LDC firms, namely, purchase of technology and technical know-how from abroad as well as from domestic sources. These sources operate as complements or substitutes in the production of technological knowledge; and the firm maximizes profits by choosing the degree to which it draws from each source.

The LDC's technology literature, on the other hand, has mainly focused on the choice of technique within a static production function framework. and on the political aspects of technology transfer from DCs to LDCs. LDCs are depicted as merely passive recipients of technology, and any role they may play in the process of technological change is ignored. Recent evidence contradicts this conventional wisdom. As one of the leaders in technology exports among LDCs and having undertaken inward looking public policies, India offers a unique case study in which many technological policy questions for LDCs could be addressed.

On infant industry grounds, India has shielded her industries from international competition both in product markets and in technology markets. In product markets, protective policies include import tariffs, import quots, and restrictions on exports all of which have effects on domestic prices. In technology markets, restrictions were imposed on foreign investment, as well as on royalty and technical fee payments to foreigners. Domestic competition was restricted by licensing schemes. It is expected that the breakdown of competition would have discouraged Indian private firms from investing in R&D. However, since this fact was not observed, questions arise: who does in-house R&D? Who purchases technology from abroad? From domestic sources? Who purchases technical assistance from abroad, or from domestic sources? What kind of innovations, if any, are the outcome of such in-house R&D efforts? Are they of the minor adaptive type or of the more basic type? What accounts for so much variation in technological expenditures between firms and between industries?

In the literature on R&D activities in India, Bhagwati and Srinivasan (1975) attempted to test whether an import substitution policy induces a higher rate of innovation than an export promotion policy in product markets; and whether restrictions on import of technology has been detrimental to India's rate of technological innovation. However, due to data inadequacy their study was inconclusive. In other studies on the same questions, relating industry level time series data on the number of approved foreign technical collaborations and the number of patents applications to changes in the government's technology policies, Desai (1982) concluded that India's inward looking technology and trade policies did indeed hinder her pace of technological innovation. Lall (1982) in contrast, by relating India's technology exports data to her protective trade and technology policies, argued that they were conducive to technological innovation, in spite of the cost of such protection. Lall (1983a) later changed his stand, however.

This paper is the first[1] attempt to explain the observed pattern of different R&D activities—including purchase of technology and technical know-how domestically and from abroad, and the production of in-house R&D—of the Indian private sector firms. The paper builds a theoretical model incorporating dynamics and uncertainty in the process of knowledge production within a statistical decision theoretic framework. This model is applied to firm level data for Indian firms. Section 2 specifies the theoretical model of R&D behaviour taking into account some of the characteristics of technological knowledge as mentioned above. Section 3 specifies the econometric methods followed. Section 4 describes the data and the empirical results. Section 5 concludes the paper with policy implications.

2. BASIC MODEL

Technological knowledge is information about the states of nature related to product or process innovation. This notion of technological knowledge was adopted by Arrow (1962), Griliches (1979), and Nelson (1982). Acquisition of techological knowledge is a deliberate economic activity like any other investment. A set of technological inputs such as in-house R&D efforts, purchase of technology from abroad as well as domestically, or technical consultation, adds to the stock of knowledge to be used immediately on the production line for further information production. The modelling of the process of knowledge accumulation is all the more complex because of the externality, indivisibility, inappropriability, unobservability, and public good characteristics associated with the production of knowledge. Moreover, the rate at which a unit of R&D input adds to the stock of knowledge varies from industry to industry depending on the R&D capability or science base of that industy (Rosenberg (1976)).[2] I assume that the accumulation of the stock

[1]Lall (1983b) initiated a firm level study on India using one year of data on manufacturing firms.

[2]There are also various sources of spill-over effects, e.g., government's investment in basic research, level of technological knowledge of other firms, the strength of the latter kind of spill-over effects will depend upon the patent law. However, in this paper, I do not consider these effects.

of knowledge follows a linear motion,

$$Z_{1\,t+1} = a_1 Z_{1t} + bR_t + w_{1t},\ t \geqslant 0,\ z_0 \text{ given} \tag{2.1}$$

where, z_{1t} is the stock of knowledge of our firm in the beginning of period t; R_t is a 5×1 vector of R&D inputs in period t, the components of which are in-house R&D expenditures, royalty paid to the foreigners, and domestic sources, technical fees paid to the foreigners, and domestic sources; $1 - a_1$ is depreciation rate of knowledge; b is the technological capability or a measure of strength of knowledge, and w_{1t} is the random shock in the process of knowledge creation in period t.

Valuation of Technological Knowledge. Due to the nonstandard characteristics of technological knowledge mentioned above, there does not and cannot exist markets for it (Arrow (1962)). I impute a shadow value to technological knowledge in the following way.

Let $P(z_{1t})$ be the probability that the firm in period t will reap an innovation that it has not reaped before, given its stock of knowledge z_{1t} in the beginning of period t. In other words, $P(z_{1t})$ is the hazard rate or exit probability of our firm in period t. Let the value η_t of an innovation at period t be the present value of the stream of future income that the innovation brings to the firm. I assume that

$$\eta_t = \eta(z_{2t},\ z_{3t},\ \xi_t), \tag{2.2}$$

where, z_{2t} = firm size at time t, z_{3t} = intensity of rivalry at time t, and ξ_t = market condition or profitability from the current line of research.

The effect of firm size on the value of technological knowledge is likely to be positive. On the one hand. larger firms, with already established name and reputation in the market, can appropriate the benefit of an innovation through easy market penetration; on the other hand, they can also use the accumulated knowledge in more than one line of production through more extensive product diversification.[3]

Lower market concentration, i.e , more rivals in an industry may lead to diminished market value of an innovation because there would be higher chances for other firms to preempt a similar innovation, or to imitate our firm's innovation, and also because our firm will have a lower market share. Furthermore, a greater monopoly power concentrated in a firm reduces its incentive for innovation as the firm may continue to earn the monopoly rent without venturing into technological innovations.

[3]It should, however, be noted that the smaller firms need not necessarily be restricted to use their knowledge only in their own production units as they can always sell it to another firm with licensing arrangements.

If we assume the cost of R&D, R_t to be quadratic in input use, $R_t'HR_t$, where H is a 5×5 matrix, then for given z_{2t}, z_{3t}, and ξ_t, one period net expected reward from z_{1t} is

$$v(z_{1t}) = \eta(z_{2t}, z_{3t}, \xi_t) \cdot P(z_{1t}) - 0.[1 - P(z_{1t})] - R_t'HR_t \qquad (2.3)$$

plus a stock of technological knowledge z_{1t+1} that will be left for the next period. If we further assume that after reaping an innovation the firm may use the accumulated knowledge for future innovative ventures, then our firm faces an infinite horizon problem. In that case, given the stochastic processes $\{z_{2t}\}$, $\{z_{3t}\}$, and $\{\xi_t\}$ that charize the environment of our firm, the expected value of a sequence of technological knowledge $\{z_{1t}\}$ obtained by applying a sequence of R&D inputs $\{R_t\}$ can be expressed as

$$V_0 = E_0 \sum_{t=0}^{\infty} \beta^t[\eta(z_{2t}, z_{3t}, \xi_t)P(z_{1t}) - R_t'HR_t] \qquad (2.4)$$

where $E_t(f)$ denotes the conditional expectation of f given information Ω_t at time t.

Assume that

$$\eta(z_{2t}, z_{3t}, \xi_t) \cdot P(z_{1t}) = Z_t'QZ_t, \qquad (2.5)$$

where, $Q = ((q_{ij}))_{i,j=1,2,\ldots,4}$ is a 4×4 matrix, $Z_t' = (z_{1t}, z_{2t}, z_{3t}, \xi_t)$.

Assuming that the stochastic processes $\{z_{2t}\}$, $\{z_{3t}\}$, and $\{\xi_t\}$ are generated by first order linear stochastic difference equations, we have the following motion of the system :

$$Z_{t+1} = AZ_t + BR_t + W_t,\ t \geqslant 0,\ Z_0 \text{ given} \qquad (2.6)$$

$$\text{where, } A = \begin{bmatrix} a_1 & 0 & 0 & 0 \\ 0 & a_2 & 0 & 0 \\ 0 & 0 & a_3 & 0 \\ 0 & 0 & 0 & a_4 \end{bmatrix},\ Z_t = \begin{bmatrix} z_{1t} \\ z_{2t} \\ z_{3t} \\ \xi_t \end{bmatrix},\ B = \begin{bmatrix} b \\ 0 \\ 0 \\ 0 \end{bmatrix},\ W_t = \begin{bmatrix} w_{1t} \\ w_{2t} \\ w_{3t} \\ w_{4t} \end{bmatrix}.$$

The manager of our firm is assumed to know the parameters of the objective function (2.4) and all the parameters of the stochastic process Z_t. In the beginning of each period t, the manager observes certain variables that constitute his information set Ω_t. All the observed variables that Granger-cause Z_t are assumed to be included in Ω_t.

The *firm's problem* is to choose an R&D investment plan $\{R_t\}$ that maximizes (2.4) subject to (2.6). Under certain regularity conditions[4]

[4]See Bertsekas (1976; 266-388).

on the matrices A, B, Q and H, an optimal solution is given by

$$R_t = z_{1t}d_1 + z_{2t}d_2 + z_{3t}d_3 + \xi_t d_4, \; t > 0, \tag{2.7}$$

where $[d_1 \mid d_2 \mid d_3 \mid d_4] = -\beta(\beta B'KB + H)^{-1}B'KA$ and K is the unique solution to the matrix Riccati equation

$$K = \beta A'[K - \beta KB(\beta B'KB + H)^{-1}B'K]A + Q. \tag{2.8}$$

The Lucas Critique and the Significance of the Riccati Equation

As I have argued before, returns from in-house R&D investment of a private firm will depend upon the evolution of market conditions and public policies. Thus the Lucas critique (1976) on policy evaluation applies to R&D investment decisions, i.e,, a firm's R&D decisions under uncertainty will depend upon its expectations about future market conditions, and policy changes. Therefore, a firm's R&D decision rule will react to the changes in the stochastic processes of these factors. The point of the critique is that instead of estimating a R&D decisison rule by throwing in arbitrarily some policy variables as regressors, one should estimate the decision rule by jointly estimating the parameters of the decision rule, objective function, and the stochastic processes generating the motion of the environment in which the firm operates.

(2.7) and the system of equations for motion (2.6) constitute the firm's decision rule. The assumption of rational expectations and the specification (2.6) of the stochastic processes have generated the cross equations parameters restrictions (2.8). These restrictions are generally used for identification of the structural parameters and also for testing the model specification. This involves highly non-linear optimization techniques which I refrain from in this paper; however, for further analysis along this line, see Raut (1986).

Although the manager of our firm could possibly observe z_{1t}, the private investors in the stock market could not. I assume that a $1 \times k$ vector of public information $X_t \subseteq \Omega_t$ that measures z_{1t} with some white noise is available to private investors. X_t's may include lagged values of a variable. The investors estimate z_{1t} as $E(z_{1t} \mid X_t)$. The new decision rule is the same as (2.7) with z_{1t} replaced by $E(z_{1t} \mid X_t)$. For our empirical purpose, I assume a linear form for this expectation as $E(z_{1t} \mid X_t) = X_t\beta$, and thus derive the firm's R&D decision rule as

$$R_t = X_t \Theta + z_{2t}d_2 + z_{3t}d_3 + \xi_t d_4, \quad t > 0, \tag{2.9}$$

where Θ is a $k \times 5$ matrix of parameters satisfying the restrictions

$$\Theta' = \beta \otimes d_1. \tag{2.10}$$

3. ECONOMETRIC SPECIFICATION

Estimation of (2.9) is complicated by the non-linear cross equations parameter restrictions, (2.10). These non-linear restrictions indeed allow us to recover the estimates of β and d_1 from Θ. If we can recover these parameters β and d_1, we can separate out the effects of a change in any X on the investor's assessment of the company's stock of knowledge using β vector from the effect of a change in stock of knowledge on the company's choice of R&D inputs using d_1 vector. Note that if β and d_1 satisfy (2.10) so do $\lambda\beta$ and d_1/λ, for any $\lambda > 0$. Therefore, not all components of β and d_1 vectors could be identified from the knowledge of Θ. I assume that scale of knowledge is standardized to such a unit that $d_{11} = 1$. A more refined econometric procedure should take into account the limited dependency of the R&D variables, cross equation restrictions in (2.7) imposed by optimal forecasting rule, and a joint estimation of all the structural as well as reduced form parameters. However, since all these involve highly non linear optimization techniques which have their own well-known problems, I have refrained from this approach. Instead I adopt the following two-step estimation procedure.

The underlying assumption in this procedure is that the X_t-variables in (2.9) are orthogonal to z_{2t}, z_{3t}, and ξ_t. In the first step, I treat $e_t = z_{2t}d_2 + z_{3t}d_3 + z_{4t}d_4$ as error term and estimate d_1 and β to minimize the sum of squared errors as follows : Let T be the number of time series observations, i.e., the number of years minus the number of lags that is used in X_t; and let N be the number of firms in the sample. Let y_1 be the $TN \times 1$ vector of first R&D input of all the firms for all the years obtained by stacking T observations of the first R&D input of a firm after T observations of the first R&D input of another firm in a column vector. Similarly $y_2, y_3, \ldots, y_5$, and $e_1, e_2, \ldots, e_5$ are defined. Let X be the $TN \times k$ vector of X_t vectors for all the firms and for all years created by the same principle as y_1. Let

$$y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_5 \end{bmatrix}, \quad e = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_5 \end{bmatrix}, \quad \mathcal{Y} = \begin{bmatrix} y_1' \\ y_2' \\ \vdots \\ y_5' \end{bmatrix}, \quad \tilde{X} = \begin{bmatrix} X & 0 & 0 & 0 & 0 \\ 0 & X & 0 & 0 & 0 \\ \cdots & \cdots & \cdots & \cdots & \cdots \\ 0 & 0 & 0 & 0 & X \end{bmatrix}, \quad d_1^{(1)} = \begin{bmatrix} d_{12} \\ \vdots \\ d_{15} \end{bmatrix}$$

The system of equations (2.9) becomes

$$y = \tilde{X}\Theta' + e \tag{3.1}$$

Sum of squared errors, $SSE = e'e = (y - \tilde{X}\Theta')'(y - \tilde{X}\Theta')$

$$= y'y - 2y'\tilde{X}\Theta' + \Theta\tilde{X}'\tilde{X}\Theta'$$

$$= y'y - 2d_1'\mathcal{Y}X\beta + d_1'd_1\beta'X'X\beta$$

$$\partial SSE/\partial\beta = 0 \Rightarrow -2d_1'\mathcal{Y}X + 2d_1'd_1\,\beta'X'X = 0$$

$$\Rightarrow \beta = (X'X)^{-1}X'\mathcal{Y}'d_1 \,/\, d_1'd_1 \qquad (3.2)$$

and $$\partial SSE \,/\, \partial d_1^{(1)} = 0 \Rightarrow -\mathcal{Y}_1^{(1)}X\beta + d_1^{(1)}\beta'X'X\beta = 0$$

$$\Rightarrow d_1^{(1)} = d_1'd_1\mathcal{Y}^{(1)}P_x\mathcal{Y}'d_1 \,/\, (d_1'\mathcal{Y}P_x\mathcal{Y}'d_1)$$

$$\Rightarrow d_1^{(1)} = A^{(1)}d_1(d_1'd_1/(d_1'Ad_1) \qquad (3.3)$$

where, $P_X = X(X'X)^{-1}X'$: OLS projection operator, $A = \mathcal{Y}P_x\mathcal{Y}'$, $A^{(1)}$ is the matrix A with its first row deleted, and $\mathcal{Y}^{(1)}$ = matrix $\mathcal{Y}$ with its first row deleted.

To estimate β and $d_1^{(1)}$, I fist solve the non-linear equations (3.3) to get an estimate of d_1, and use this estimate in (3.2) to get an estimate of β. One main problem with this estimation procedure is that we do not know the properties of these estimates, among which the standard errors of the estimates. While jacknifing, bootstrapping or sub-sampling procedure could yield a non-parametric way of calculating standard errors of the estimate (see Effron and Gong (1983), and Hartigan (1975), they turn out to be highly computer intensive for our large data set. Instead, I follow a procedure similar to Hartigan's sub-sampling procedure as follows.

I delete 10 random cross section observations (i.e., firms) from the original sample to create a subsample, and this way I create 5 sub-samples. For each sub-sample, I compute the estimates of β and d_1 and take the dispersion matrices of β and d_1 as the estimated dispersion matrices of β and d_1. The estimates regarding d_1 are shown in Table 5, and that for β are shown in Table 7.

In the second step, I employ Zellner seemingly unrelated regression procedure on the residuals $e_1, e_2, \ldots, e_5$, taking exogenous variables as z_2, z_3, and industry dummies, and treating ξ as the error term. This provides estimates for d_2, and d_3. These estimates are shown in Table 5. Table 6 shows the decomposition of total variance of each R&D input as explained by the factors—knowldge, and firm size and market structure both together.

The Data and Empirical Results

The data for the present study come from a sample of top 1,200 firms in terms of total assets in the Indian manufacturing sector. The data on R&D expenditures, royalty payments, technical fee payments, exports and imports of capital goods come from the firms' annual reports; the patent data come from the Gazette of India; and the remaining data come from the Bombay Stock Exchange Directories. The complete set of data on all the relevant variables were available only for 366 firms and for the years 1975 to 1981. However, this sample covers the entire range of technologies which together constitute the over-all industry in our analysis. The variables in our data set are standardized to mean zero and variance one within the overall sample. The variables are defined as follows :

Endogenous variables

RDEXP = research and development expenditures

ROYLDOM = domestic royalty payment

TKFEEDOM = technical fee paid to domestic sources

ROYLFRN = royalty paid to foreign sources

TKFEEFRN = technical fee paid to foreign sources

Exogenous Variables that estimate stock of knowledge

IMPCAP = import of capital goods

NET SALE = net sales

NOPAT = no. of patents applied

RMV = range in stock prices within a year

EXPORT = export

PBTX = profit before tax

INT = interest paid to the shareholders

Other factors

SIZE = firm size

CONCEN = industry concentration, i.e. four firm ratio.

X_{-i} denotes ith lag value of the variable X.

I divide the firms in our sample into three subgroups. The first subgroup consists of 127 firms in *Light industries* (including manufacture of wood and wood products, food products, beverages, tobacco products, textiles, paper and paper products). The second subgroup consists of 163 firms in *Petro-Chemical industries* (including manufacture of rubber, plastic, petroleum, coal and coal products, chemical and chemical products including pharmaceuticals, and non-metallic minerals). The third subgroup consists of 167 firms in *Heavy industries* (including manufacture of machinery, machine tools and parts, electrical machinery, electrical appliances and parts, basic metals and metal products).

Table 1 gives the means, coefficients of variation, and the percentages of firms participating in each of the R&D activities for all three industrial sectors as well as for the over-all industry. It is clear from the last column of the table that on average Indian firms spend a proportionately higher amount of resources on purchasing technology and technical know-how from abroad as compared to domestic procurement and development in in-house R&D laboratories; moreover, a high percentage of foreign technology is bought by only a few firms. It is also clear that only about 20% participate in these R&D activities.

TABLE 1

AVERAGE EXAENDITURES ON DIFFERENT R&D ACTIVITIES

(Rs. '000 per year)

Variables	*Light Industry*	*Petro-Chemical Industry*	*Heavy Industry*	*Over-all Industry*
RDEXP				
mean	486.73	1442.58	1907.69	1312.28
% of firms	25.86	23.33	23.13	24.04
C.V.	244.20	283.82	279.17	309.08
ROYLDOM				
mean	1290.64	1110.54	868.12	1057.76
% of firms	23.28	23.33	24.38	23.77
C.V.	260.74	149.99	198.67	220.04
ROYLFRN				
mean	800.59	429.65	553603.33	291281.28
% of firms	14.66	22.22	25.63	31.31
C.V.	146.35	155.94	639.63	881.38
TKFEEDOM				
mean	657.78	892.78	749.04	756.71
% of firms	15.52	16.67	21.25	18.31
C.V.	157.87	96.57	228.97	182.78
TKFEEFRN				
mean	697.88	1503.53	17635.01	9060.84
% of firms	18.10	25.56	23.63	23.22
C.V.	131.13	237.99	575.87	779.15
No. of firms	127	76	163	366

A closer look at Table 1 reveals that participation rates do not vary much across sectors, and that much of the high variation in ROYLFRN and TKFEEFRN takes place within heavy industry. The firms in the heavy industries on average spend a large amount of their resources on purchasing techonlogy and technical know-how from abroad as compared to the other two industries; they also have larger expenditures on other R&D activities. The expenditures of the firms in heavy industries on these two R&D activitiès show the highest coefficient of variation, followed by expenditures on in-house R&D. The light industry firms spend a relatively higher percentage of their resources on ROYLDOM and ROYLFRN as compared to their expenditures on other R&D activities, although there is high variation among firms. More interesting is the fact that the mean and coefficient of variation of ROYLDOM in this industry are the highest of the three industries.

The petro-chemical industries, on the other hand, spend a relatively large amount on in-house R&D and the purchase of technical assistance from abroad, both expenditures exhibiting highest coefficients of variation as compared to amounts spent on other R&D activities. The next highest coefficient of variation is that of domestic technology purchases. It might be concluded from these expenditures patterns that the heavy industries draw their source (origin) of technology from predominantlv foreign purchases accompanied by foreign technical assistance; the light industries source (origin) comes mainly from domestic purchases complemented to some extent by foreign technology and in-house R&D, while the petro-chemical industries' source is a combination of in-house laboratories research and technology bought from domestic and foreign sources. Moreover, it is also clear that the R & D activity in which an industry specializes exhibits the highest coefficient of variation. This leads to the question why different industries specialize in different R & D inputs.

Tables 2-4 describe the interaction among R&D inputs. Tabie 2 gives as a percentage of all the firms doing in-house R&D, the firms engaged in each R&D activity and reports the averages for expenditures on each R&D activity for firms with and without in-house R&D. Tables 3 and 4 give similar information on interaction of ROYLDOM and ROYLFRN with other inputs.

From these tables it is clear that in the light and petro-chemical industries firms that do in-house R&D tend to spend more on purchasing technology domestically than from abroad. As the average ROYLDOM is much higher than the average RDEXP for the firms doing both ROYLDOM and RDEXP in these two industries, this suggests that these firms do not spend enough resources for further development of locally procured technology. On the other hand, for firms that do both RDEXP and ROYLFRN, their average RDEXP is much higher than the average

TABLE 2

CHARACTERISTICS OF FIRMS DOING IN-HOUSE R&D

(Rs. '000 per year)

Variables	*Light Industry*	*Petro-Chemical Industry*	*Heavy Industry*
ROYLDOM			
% of firms	37.04	28.57	38.46
mean	2168.99	1999.10	1463.16
mean without	773.96	755.12	496.22
ROYLFRN			
% of firms	29.41	30.00	43.90
mean with	415.33	326.93	1260592.50
mean without	961.04	473.67	307.44
TKFEEDOM			
% of firms	41.18	33.33	41.18
mean wlth	344.13	896 01	441.01
mean without	857.40	896.17	964.66
TKFEEFRN			
% of firms	33.33	34.78	41.40
mean with	535.04	2919.04	41096.02
mean without	629.26	748.59	1016.80
No. of firms doing RDEXP	30	21	37

Note : % firms : out of all firms doing RDEXP, the % engaged in the activity;
with : for the firms with positive RDEXP;
without : for the firms with zero RDEXP.

TABLE 3

CHARATERISTICS OF FIRMS DOING ROYLDOM

(Rs. '000 per year)

Variables	*Light Industry*	*Petro-Chemical Industry*	*Heavy Industry*
RDEXP			
% of firms	33.33	28.57	40.54
mean with	132.64	874.47	2876.96
mean without	663.78	1669.82	1246.81
ROYLFRN			
% of firms	64.71	50.00	56.10
mean with	1083.06	521.60	658.21
mean without	282.73	337.69	1260144.32
TKFEEDOM			
% of firms	50.00	46.67	55.88
mean with	957.67	666.62	912.57
mean without	357.92	1090.67	541.91
TKFEEFRN			
% of firms	52.38	21.74	36.59
mean with	734.90	616.35	2846.26
mean without	447.10	1749.97	26166.97
No. of firms doing ROYLDOM	27	21	39

Note : % of firms : out of all firms doing ROYLDOM, the % engaged in the activity ;
with : for the firms with positive ROYLDOM;
without : for the firms with zero ROYLDOM.

TABLE 4

CHARACTERISTICS OF FIRMS DOING ROYLFRN

(Rs. '000 per year)

Variables	*Light Industry*	*Petro-Chemical Industry*	*Heavy Industry*
RDEXP			
% of firms	16.67	28.57	48.65
mean with	1441.96	3983.44	3447.89
mean without	295.69	426.23	448.54
ROYLDOM			
% of firms	40.74	47.62	58.97
mean with	2678,22	818.23	1033.29
mean without	336.66	1376.28	630.68
TKFEEDOM			
% of firms	27.78	46.67	61.76
mean with	957.47	487.09	979.06
mean without	542.53	1247.76	377.48
TKFEEFRN			
% of firms	38.10	43.48	63.41
mean with	912.83	551.43	26679.86
mean without	404.02	2235.91	1957.26
No. of firms doing ROYLFRN	17	20	41

Note : % of firms : out of all firms doing ROYLFRN, the % engaged in the activity;
with : for the firms with positive ROYLFRN;
without : for the firms with zero ROYLFRN.

ROYLFRN (in fact this average RDEXP is much higher than the average RDEXP of the firms doing both RDEXP and ROYLDOM, and a few firms do both ROYLDOM, ROYLFRN together with RDEXP). This suggests that for these firms large resources go into in-house development and improvement of technology purchased abroad. This, together with the fact that RDEXP of the firms without ROYLFRN is much lower than for those with ROYLFRN, may indicate that the main source of ideas for further technological innovation (or improvement) in in-house laboratories for these two industries is purchased foreign technology. The purchase of local technology by firms doing in-house R&D might be required for sheer survival in the competitive environment which faces a firm during the development of an improved technology in its own laboratory. A closer look at Table 2 reveals that even though purchase of foreign technology induces more in-house R&D in both the light and petro-chemical industries, high in-house R&D expenditures of the petro-chemical industry (unlike that of light industry) are associated with high purchase of foreign technical assistance. At this stage it is difficult to discern which way causality runs among these R&D expenditures.

The story for the firms doing in-house R&D in heavy industry is about the same as the petro-chemical industry except that, as the average RDEXP of those firms doing both RDEXP and ROYLFRN is much lower than the average ROYLFRN, it may be the case that this industry is not doing much of basic innovation nor of improvement of purchased foreign technology. Its in-house R&D activities might be limited to modifying purchased foreign technology to make it suitable to the local environment. Unlike the petro-chemical industry, heavy industry's RDEXP is not associated with high foreign technical assistance. As for the firms not doing in-house R&D, it appears from these tables that they depend on purchase of technology and technical assistance from both domestic and foreign sources to maintain competitiveness and expected profitability. These firms, moreover, make up the major category in our sample.

Parameter Estimates

Table 5 shows that an increment in a heavy industry firms's stock of knowledge induces an increase in RDEXP, ROYLFRN, TKFEEFRN, and a reduction in ROYLDOM and TKFEEDOM. With some qualification, the same holds for firms in light industry; when the stock of technological knowledge of these two industries is increased to such levels that it results in the same increment in RDEXPs of firms in both industries, the heavy industry's ROYLFRN and TKFEEFRN are more affected than those of the light industry. In the petro-chemical industry, however, the firms's response to an increase in technological knowledge is to substitute ROYLDOM, TKFEEDOM, and TKFEEFRN for more in-house R&D and acquisition of domestic technical assistance.

In this study, firm size is measured by the firm's total assets. The effects of firms size on R&D activities are shown in Table 5. In the heavy industries, an increase in firm size induces a firm to increase its expenditure on in-house R&D, domestic purchase of technology and technical know-how, and to reduce its expenditure on technology from abroad. On the other hand, an increase in the size of a firm in the petro-chemical industry induces it to spend more resources on the remaining R&D inputs, with relatively large amounts on purchasing technology and

TABLE 5

THE ESTIMATES OF d_1, d_2 and d_3 COEFFICIENTS

R&D inputs	Light Industry Knowledge	Light Industry Size	Light Industry Concen	Petro-Chemical Industry Knowledge	Petro-Chemical Industry Size	Petro-Chemical Industry Concen	Heavy Industry Knowledge	Heavy Industry Size	Heavy Industry Concen
RDEXP	1.0000	.0003	—.0272	1.0000	.0055	1.1890	1.0000	.1424	—.0564
		(.08)	(.21)		(.44)	(1.06)		(2.84)	(.07)
ROYLDOM	—.0645	.0381	.2590	—.1104	.3180	—7.636	—.0296	.0586	—.5255
	(.0011)	(1.49)	(.24)	(.1475)	(3.86)	(.99)	(.0011)	(2.17)	(1.27)
ROYLFRN	.0354	—.0007	—.0030	—.0023	.0001	—.0007	3.0[illegible]20	—.0307	.0070
	(.0014)	(2.11)	(.21)	(.0440)	(1.07)	(.08)	(.0009)	(3.74)	(.06)
TKFEEDOM	—.1745	—.0054	—.0054	.1070	.1479	1.0840	—.0330	.1060	—.2720
	(.0067)	(.43)	(.01)	(.2148)	(2.36)	(.19)	(.0025)	(2.47)	(.41)
TKFEEFRN	.0299	.0098	.0441	—.0005	.0250	.1380	2.5592	—.0241	—.0090
	(.0014)	(3.21)	(.35)	(.0577)	(9.09)	(.56)	(.0011)	(1.31)	(.03)

Note : The figures in bracket under Knowledge Column are standard errors, and other columns are absolute value of *t*-statistics.

technical know-how domestically, but without causing any significant effect on R&D expenditures. In the light industries, an inerease in firm size would marginally increase the expenditure on domestic purchases of technology, and reduce purchases of foreign technology slightly without causing a significant effect on other inputs. The most significant effects of an increase in the firm size, therefore, appear to be an increase in the domestic purchase of technology and technical know-how by the firms in the petro-chemical industry, an increase in in-house R&D expenditure and domestic purchase of technical know-how by the heavy industry firms, and an increase in the purchase of domestic technology in the light industry firms; the other effects are either statistically insignificant or numerically very small.

The effects of market structure or concentration (Table 5), as measured by the four-firm ratio, seem to be insignificant except for an inducement to substitute domestic procurement of technology with in-house development in the petro-chemical industry.

Table 6 shows that the level of technological knowledge alone explains 89% 92% and 16% of the total variation in the R&D expenditures of the light, petro-chemical, and heavy industries, respectively: it also explains

TABLE 6

DECOMPOSITION OF TOTAL VARIANCES OF DIFFERENT R&D INPUTS AS EXPLAINED BY DIFFERENT FACTORS

Industry	*Factors*	*RDEXP*	*ROYLDOM*	*ROYLFRN*	*TKFEEDOM*	*TKFEEFRN*
Light						
	knowledge	89.42	.15	.03	3.81	.91
	market	.24	6.00	1.80	3.08	2.42
	residual	10.34	93.85	98.16	93.11	96.67
	total	100.00	100.00	100.00	100.00	100.00
Petro-Chamical						
	knowledge	91.70	.33	6.98	.43	.01
	market	.06	5.49	80.93	1.60	18.11
	residual	8.23	94.18	12.09	97.96	81·88
	total	100.000	100.00	100.00	100.00	100.00
Heavy						
	knowledge	15.60	.04	98.46	.03	90.09
	market	1.47	3.48	.04	1.90	.03
	residual	82.93	96.48	1.50	98.06	9.88
	total	100.00	100.00	100.00	100.00	100.00

Note : market factor includes CONCEN and SIZE.

more than 90% of the variation in the expenditures on technology and technical know-how purchased from abroad by the heavy industry firms. Stock of technological knowledge explains very little of the variation of the remaining R&D variables. Except for expenditures on purchase of technology and technical know-how from abroad in the petro-chemical industries, the firm size, concentration ratio, and industry dummies account for a very small part of total variation in R&D inputs.

The magnitude of residual variances suggests that this model does not give a full explanation of the total variation of ROYLDOM and TKFEEDOM for any industrial subgroups, nor of ROYLFRN and TKFEEFRN in the light and petro-chemical industries. Further research is necessary to address the problem.

Let us now turn to the dynamic effects (see beta coefficients in Table 7) of the variables estimating the stock of knowledge. (I present only the effects on in-house R&D investment. The effects on other four R&D inputs are obtained by multiplying these effects by the corresponding d_1-coefficients, of Table 5.) Although some of the negative signs of these coefficients, which may have arisen due to multi-collinearity, are difficult to interpret, and although some parameters estimates are low possibly due to the limited dependent variable problem, a few conclusions can still be drawn. First, the gestation period for in-house R&D investments is on average a year in the light industry, two years in the petro-chemical industry; it could exceed two years in the heavy industry before these investments bring maximum contribution to the formation of technological knowledge. However, it is not known whether the coefficients of RDEXP_{-i}, for $i > 2$ would really be higher than the ones included (I could not carry out the investigation further owing to the paucity of data). However, it supports my contention that the technological knowldge base of heavy indutry is not as mature as those of the light and petro-chemical industries.

Second, from a firm's purchase of technology in the light and petro-chemical industry in any year the private investors *a posteriori* feel that the firm's stock of knowledge has been reduced relative to others in the industry, and this purchased technology through the process of learning-by-doing contributes a great deal to the firm's stock of knowledge within a period of two years. In fact, this stock enlarges so much that they could now take up more basic research; this is reflected in their high propensity to spend on in-house R&D. This effect is, however, greater for foreign technology than for domestic technology. The case of heavy indusry is quite different : from the coefficients of ROYLFRN_{-1} and ROYLFRN_{-2} it is evident that a purchase of foreign technology in this industry induces only a marginal increase in the in-house R&D expenditures, which suggests that they engage mainly in the adaptive R&D,

TABLE 7

ESTIMATES OF COEFFICIENTS

Variables	*Light industry*	*Petro-Chemical Industry*	*Heavy Industry*
RDEXP_1	.76421	.28028	.00270
	(.0021)	(.0837)	(.8E-5)
ROYLDOM_1	—.00516	—.07072	—.0074
	(.0011)	(.0952)	(.0040)
ROYLFRN_1	—26.97310	—10.43500	.49306
	(.1515)	(19.6251)	(.0244)
TKFEEDOM_1	—.08338	.10020	—.00241
	(.0020)	(.2084)	(.0001)
TKFEEFRN_1	.12673	—.19774	.01269
	(.0126)	(.3256)	(.5E-5)
IMRCAP_1	—.00135	.08608	.03489
	(.0001)	(.0777)	(.2E-4)
NQRAT_1	.04696	.00849	—.10392
	(.00004)	(.0037)	(.4E-5)
EXPORT_1	—.08531	—.52191	—.02200
	(.0009)	(.1902)	(.7E-5)
PBTX_1	—.00315	—.01987	.00124
	(.4E-4)	(.0246)	(.0039)
NSALF_1	—.02101	.09382	.00592
	(.5E-4)	(.0568)	(.9E-5)
RMV_1	.00007	—.06586	.00421
	(.2E-5)	(.0301)	(.0001)
INT_1	—.00298	.00807	—.00801
	(.1E-9)	(.0229)	(.5E-5)

Table 7 (*contd. on page* 226)

Table 7 (*contd. from page* 225)

Variable	*Light Industry*	*Petro-Chemical Industry*	*Heavy Industry*
RDEXP_2	.23962	.75539	.04125
	(.0003)	(.0207)	(.2E-4)
ROYLDOM_2	—.05736	.02013	.00116
	(.0002)	(.0018)	(.4E-4)
ROYLFRN_2	26.67080	11.20720	—.22108
	(.1423)	(19.7556)	(0244)
TKFEEDOM_2	—.06622	—.03945	.00033
	(.0035)	(.0586)	(.2E-4)
TKFEEFRN_2	—.00148	.49217	.00916
	(.0214)	(.3930)	(.1E-4)
MCAP_2	.00037	—.14709	—.01590
	(.3E-5)	(.0676)	(.1E-4)
NOPAT_2	—.00532	.01280	—.00111
	(.1E-4)	(.0067)	(.3E-5)
EXPORT_2	.08474	—.14953	.04052
	(.0008)	(.0172)	(.1E-4)
PBTX_2	.000445	—.00809	.00040
	(.0011)	(.0095)	(.3E-5)
NSALE_2	.02358	—.00127	.00097
	(.1E-4)	(.0086)	(.8E-5)
RMV_2	.00009	.09796	.00100
	(.2E-6)	(.0258)	(.3E-4)
INT_2	.00163	—.01855	.00479
	(.0014)	(.0122)	(.9E-5)

Note : Figures in brackets are standard errors based on 5 subsamples.

Third, from the coefficients of $EXPORT_{-1}$ and $EXPORT_{-2}$ in Table 7 it is clear that the export promotion policy as such is not conducive to higher pace of in-house development of technology.

Fourth, while patent protection in light or petro-chemical industries stimulates further in-house research, its impact on the in-house research efforts of the firms in heavy industry is negative.

7 Conclusions

This paper explains the observed pattern of Indian private firms' expenditures on purchases of technology and technical know-how domestically and abroad, and on in-house R&D. The following conclusions emerge.

While we do not know whether the MRTP (Monopoly Restrictive Trade Practices) Act and different licensing policies have achieved the original intent of curbing the growth of larger firms in areas where small and medium enterprises could grow, it is apparent from the results of the paper that the larger firms in the heavy and petro-chemical industries tend to substitute domestic for foreign technology. Moreover, these larger firms in the heavy industry tend to substitute in-house development for foreign technology. In the petro-chemical industry, however, larger firms purchase more technology and technical know-how abroad and especially from domestic sources, but size shows no significant effcct on in-house R&D expenditures. Thus in a word, larger firms in all three industries tend to foster technological change at a faster pace. In addition, in the light and petro-chemical industries they accomplish to some extent the goal of technological self-reliance.

Market structure or monopoly power seems to have no significant impact on the light industry's R&D activities. In the heavy and petro-chemical industries, as the concentration ratio rises, firms reduce purchases of technology from domestic sources without changing any other R&D activities significantly, though in the case of the petro-chemical industry this is off-set to some extent by an increase in in-house R&D efforts. More concentration and less competition make heavy industry retain obsolete technology, though an increase in in-house R&D expenditures is also observed. The observed diversity among industries may be the result of market structure—while the petro-chemical industry is more open to price competition, both domestic and international, the heavy industry lacks competition as a result of Government of India's price support policies among which tariff protection. The Indian automobile industry was an example of domestic oligopoly protected by government policy against import competition.

The validity of export promotion as inducement to innovation is rejected in light of the present analysis. The impact of the present patent protection policy, is rather mixed. This calls for a reconsideration of the terms of the revised Patent Act of 1973, and also a careful examination of export policies.

The paper also finds that the three industry groups specialize in three different R&D activities : light industry in domestic purchase of technology, the petro-chemical in in-house R&D, and heavy industry in purchase of foreign technology. The source of ideas for further innovation is predominantly purchased foreign technology. While the petro-chemical and light industries are able to do more basic research, heavy industry tends to do only minor adaptive research.

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