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TECHNOLOGY PRODUCTION AND TECHNOLOGY PURCHASE IN INDIAN INDUSTRY: AN ECONOMETRIC ANALYSIS

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ABSTRACT

TECHNOLOGY, PRODUCTION AND TECHNOLOGY PURCHASE IN INDIAN INDUSTRY: AN ECONOMETRIC ANALYSIS

Industrial firms in low income countries face somewhat different incentives for investment in R&D than do firms in industrialized countries. In particular, they are at a competitive disadvantage with respect to selling technology upstream in the industrialized countries. Technology supplied from upstream industrial firms provides them with a strong incentive to purchase technology in various forms as opposed to engaging in their own R&D.

In this study an econometric analysis of the decisions of Indian firms to invest in their own R&D and to purchase technology (through licensing agreements) is undertaken. These decisions are treated as being jointly determined by characteristics of Indian industries, Indian prices, and the supply of purchasable foreign technology. The study finds that industrial structure, firm size, and public and private ownership influence the mix of own R&D and technology purchase. The pool of purchasable foreign technology induces both increased adaptive R&D and technology purchase by Indian firms.

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1. Introduction

While there is a large literature on the determinants of technological innovation (Kamien and Schwartz, 1975, 1982; Scherer, 1980, 1986; Griliches, 1984), most of it has been in the context of developed countries, particularly the United States. There is little systematic study of the determinants of inventive activity in the manufacturing sectors of less-developed countries. Yet in these countries inventive activity, although at a low level, appears to be growing rapidly. It is quite possibly an important factor in productivity growth in less-developed countries because of the scope for complementarity between domestic invention and imitation or adaptation of technology from abroad.

In this paper, we study the determinants of inventive activity in the manufacturing sector of India, using industry-level data for the period 1960-70. Our approach differs from earlier approaches in that we embed the demand for inventive activity in a system of input demand equations. Since licensing of foreign technology is an often-used alternative (possibly complementary) to in-house research and development for firms in less-developed countries, the demand for foreign technology is also included in the demand system. This permits us to look at the substitutability/complementarity relationships between own-produced and purchased technology and between each of these technologies and other variable inputs. Since we include variables measuring the presence of multinationals, level of international inventive activity, size of the public sector, and average firm size in the demand equations, we are able to analyze the reduced-form impact of these variables on the demand for own-produced and purchased technology.

To anticipate our empirical results, we find that inventive activity is related inversely to average firm size in the Indian context. International inventive activity has strong positive effects on the demand for both local innovation and foreign technology, which suggests that it increases the pool of inventions that can be both imitated within and sold to India. Foreign ownership is associated with less local innovation, while state ownership is associated with more local innovation, but only in the chemical industries.

2. Local Innovation and Foreign Technology Purchase in India

Although the level of inventive activity in India is low relative to developed and semi-industrialized countries (e.g., Brazil and South Korea), it has been growing quite rapidly over time. Table 1 shows the expenditures on research and development (R&D) and on foreign technology purchase by all private and public sector companies in India from 1964-65 to 1969-70. R&D expenditures grew at a trend rate of 26.0 percent per annum over this short period. Expenditures on foreign technology purchase increased at a rate of 16.2 percent per annum.[1]

Table 1. R & D expenditures and payments for foreign technology: Indian industries, 1964-65 to 1969-70. (In Millions of Rupees)

Year	R & D Expenditure on Current and Capital Account	Royalty and Technical Fee Payments for Foreign Technology
1964-65	105.1	76.9
1965-66	143.7	101.6
1966-67	178.2	142.4
1967-68	261.7	133.3
1968-69	310.7	162.2
1969-70	378.5	183.1
Trend rate of growth over the period	26.0	16.2

Source: Reserve Bank of India, Foreign Collaboration in Indian Industry: Second Survey Report, 1974, Bombay, India, pp.25 & 138.

In Table 2, the number of patents granted to Indian nationals -- a crude measure of inventive output[2] -- are shown for the period 1954-57 to 1967-70 for each of 15 major industries. The average rate of growth of patenting by nationals was 8.4 percent per annum over the period, with no industry experiencing a decline in patenting and almost half of the industries experiencing a growth of patenting in excess of 10 percent per annum. The decade of the 1960s thus saw a rapid growth of both inventive activity and foreign technology purchase in Indian manufacturing.

3. The Model

We use the cost function framework to study the twin demands for inventive activity and foreign technology by firms in manufacturing industries. Using the duality theorems of Uzawa (1964), Shepard (1970), and McFadden (1978), it is possible to completely describe the nature of the production technology from the cost function. In what follows, we shall assume that firms minimize the costs of producing a given output subject to a production function that can be shifted or altered by inventive activity and foreign technology, among other things.

Duality theory imposes strict restrictions on the specification and estimation of factor demand equations. Symmetry restrictions across equations arising out of cost-minimizing behavior by economic agents, as well as homogeneity restrictions derived from the underlying production technology, are generally imposed in the estimation of factor demand systems. These restrictions are not very difficult to implement when

Table 2. Number of patents granted to nationals in India, by industry and year, 1954-57 to 1967-70.

Industry	Year 1954-57	1958-61	1962-66	1967-70	Trend rate of growth from 1954-57 to 1967-70
Food processing	26	69	123	132	12.4
Textile manufacturing	52	76	92	86	3.8
Jute manufacturing	1	2	4	3	8.9
Textile products	4	6	9	19	11.9
Wood products	4	5	7	8	5.6
Paper and printing	21	28	54	50	7.4
Leather	22	13	18	23	1.2
Rubber and plastics	18	33	55	59	9.3
Chemicals	46	92	137	251	12.7
Non-metallic mineral products	25	54	72	85	9.0
Basic metals	1	2	12	7	17.2
Metal products	2	7	9	14	14.0
Machinery	10	37	48	74	14.4
Electrical equipment	4	26	13	16	7.8
Transport equipment	8	36	34	47	12.0
All industries	244	486	687	742	8.4

estimating a complete demand system, i.e., one in which quantity and price data are available for all inputs. In this paper, the presence of two inputs -- inventive activity and foreign technology -- for which price data are not readily available necessitates a somewhat flexible functional form for the demand system

Among the three commonly-used flexible functional forms for cost functions, viz., the generalized Leontief, translog, and generalized quadratic, only the last yields a system of input demand equations that is estimable with some missing input price data. We, therefore, use the generalized quadratic cost function (Fuss, et.al, 1978, Lau, 1978) given by:

$$\text{(1)} \qquad C = \sum_i a_i p_i + \sum_i \sum_j b_{ij} p_i (p_j/p_n) + c_1 Q + c_2 Q^2 + \sum_i d_i p_i Q + e_{1k} Z_k + e_{2k} Z_k^2 + \sum_k f_{ik} p_i Z_k + \sum_k g_{ik} p_i Z_k^2,$$

$$b_{ij} = b_{ji} \quad \forall \quad i,j=1, n-1; \quad i \neq j;$$

which is linear homogeneous in prices, and in which C = total costs, Q = total output, p_i = price of the ith variable input, and Z_k = level of the kth fixed factor.

Using Shephard's lemma and differentiating (1) with respect to p_i, we obtain the input demand equations:

$$\text{(2)} \qquad X_i = \partial C/\partial p_i = a_i + \sum_j b_{ij} (p_j/p_n) + d_i Q + \sum_k f_{ik} Z_k + \sum_k g_{ik} Z_k^2, \quad \forall \ i,$$

$$b_{ij} = b_{ji}, \quad \forall \ i,j=1,n-1; \quad i \neq j;$$

where X_i = quantity of the ith variable input. It is the system in equation (2) that is estimated in this paper.

In estimating cost-minimizing industry demand equations, two important assumptions are maintained. First, implicit in the use of industry-level data is the assumption that the average firm in an industry is representative of all the firms in that industry. The various implications of this assumption have been discussed in a number of other studies (Griliches, 1967; Zarembka, 1970; Dennis and Smith, 1978). However, this practice is common enough in the literature that we adopt it here, albeit with the necessary qualifications. Second, it is assumed that input prices and output are exogenous variables at the industry level. This is not an unreasonable assumption in the Indian context, where government intervention in the form of capacity licensing and price setting has been very common, at least during the decade of the 1960s (Bhagwati and Desai, 1970). It is, therefore, not unrealistic to characterize Indian firm behavior as one of minimizing costs for given levels of input prices and output.

The treatment of foreign technology and local inventive activity as variable factors of production requires more justification. These activities are normally viewed in a fixed factor or investment framework. Our reasons for treating them as variable inputs are twofold. First, both activities have a real element of variability. Second, the conventional investment framework has not proved to be very illuminating for the questions that we have in mind.

Technology purchase is quite variable since many of the contractual arrangements are quite short term in nature. Technical assistance, for example, is often provided only for short periods, and arrangements can be changed quite rapidly. Invention by Indian firms also tends to be quite adaptive, and, while it has an investment component, the time period over which the service flow from the investment is positive is relatively short. This is because "follow-on" adaptive inventions erode the rents associated with any given invention. Indian inventions have a high degree of erosion relative to inventions in developed countries because almost all invention is adaptive. It takes the form of a modification of other inventions. A large flow of developed country inventions then induces a high rate of adapted inventions, many of which do not qualify for patent protection. Those qualifying for patent protection tend to have a very short economic life.

4. Data and Estimation

The variables used in the analysis, and their means and standard deviations, are listed in Table 3 (see Appendix for data sources). A total of five variable inputs are included: production labor, non-production labor, fuel, patenting in India by nationals, and royalty and technical fee payments for foreign technology. Capital is treated as a fixed factor, since government capacity licensing makes capital stock exogenous to the firm's decisions, at least in the short run.

While data on production labor are available in man-hours, data on non-production labor are available only in numbers of employees. Patenting by nationals in India is used as a proxy for local inventive input (and not for inventive output, as it is the case in much of the literature), since industry-specific data on R&D expenditures or R&D personnel are not available for the period 1960-70. While patenting is a crude proxy for inventive activity, particularly in India where a system of utility models or "petty" patents (minor adaptive inventions) does not exist, almost all other quantitative measures of inventive activity, including R&D expenditures, are also likely to be crude proxies for inventive input. Most of the R&D conducted in less-developed countries is informal or 'blue-collar' R&D, which is largely conducted outside the formal R&D divisions of companies.

Foreign technology input is proxied by the total payments made by firms in an industry to foreign suppliers for the purchase of know-how or technology. The payments include both royalties as well as (lump-sum) technical fees. The specification of foreign technology in expenditure (instead of quantity) terms is forced on us by the data. We do not have industry-specific data on, say, the number of foreign technology collaborations. However, it could be argued that the foreign technology variable we use is sensitive to quality differentials in technologies purchased across industries in a way that the <u>number</u> of foreign technology collaborations would not be. Of course, the interpretation of our empirical results will be affected by the specification of the foreign technology variable in expenditure terms. We note that, even if the number of patents and payments for foreign technology are poor proxies for local inventive activity and foreign technology, respectively, since they are treated as dependent variables in our analysis, errors of measurement in these variables are part of the general error structure of the model.

Table 3. Variables means: Indian industries, 1960-70.

	Industries			
	Light[d]	Chemical[e]	Engineering[f]	All
Production labor[a] (in man-hours)	687,635	1,092,343	864,790	836,425
Number of non-production workers[a]	32	112	252	122
Fuel consumption (= Rupee Expenditure on Fuel ÷ Fuel Price Index)[a]	1,143	12,955	3,341	4,509
Technology imports (Royalty & technical fee payments in Rupees for foreign know-how)[a]	33,510	57,451	948,175	339,492
Domestic patenting (No. of patents x 1000 granted to nationals in India)[a]	432	183	215	305
W_p (Hourly wage rate in Rupees for production labor)	0.52	1.00	0.83	0.73
W_N (Annual wage rate in Rupees for non-production workers)	3,948	8,073	5,119	5,256
P_F (Price index for fuel)[b]	120	120	120	120
USPATNTS (Cum. no. of patents granted in USA over previous 5 years)[a]	126	326	1,389	586
FORSHARE (Share of equity held by foreigners during 1965-70)[c]	26.81	13.63	23.22	22.68
PUBSHARE (Share of production in public-sector enterprises during 1970-73)[c]	3.70	15.75	18.17	11.15
FIXEDCAP (Fixed capital stock in Rupees)[a]	1,008,852	19,517,808	4,217,698	6,241,176
OUTPUT (Gross output in Rupees)[a]	5,150,564	25,268,988	6,224,962	10,005,713
Number of observations	192	96	141	429

[a]Variable has been divided by the total number of firms in the industry. The variable means, therefore, refer to the average firm in the industry.

[b]Variable varies only with time.

[c]Time-invariant variable.

[d]Includes all food manufacturing, beverage, tobacco, textile spinning and weaving, and knitting industries.

[e]Includes basic industrial chemicals (including fertilizer), pharmaceuticals, miscellaneous chemical products, petroleum and coal products, and cement industries.

[f]Includes metal products, machinery, electrical machinery and equipment, transport equipment, railroad equipment, and automobile and cycle industries.

We use data on three prices, viz., wage rates for production labor, wage rates for non-production employees, and price (index) of fuel. The latter varies only over time, not across industries. The fixed factors included in the demand system are fixed capital stock, share of industry equity held by foreigners, share of industry output produced in public-sector or state-owned firms, and the cumulative number of patents granted within the same industry in the United States (to both nationals and foreigners) during the previous five-year period. In addition, all of the preceding four variables are included in quadratic (i.e., squared) form in the demand equations to capture nonlinearities in demand with respect to the exogenous variables.

The number of patents granted in the United States is a proxy for the supply of international inventions or technology. Insofar as the demand for foreign technology by Indian firms may be constrained by the pool or supply of internationally-available technologies, it is important to include the latter in the demand system. Additionally, insofar as much of Indian inventive activity involves modification and adaptation of technologies already developed elsewhere, the international supply of technology may act as a constraint to Indian inventive activity as well. The impact of international inventions on the demand for foreign technology and domestic inventive activity in Indian manufacturing has important policy implications and is an important concern of this paper.

The total sample includes observations on 50 three- and four-digit manufacturing industries over the period 1960-70. The sample of industries has been divided into three groups: light industries, comprising food processing, beverages and tobacco, textile spinning and weaving, and knitting industries; chemical industries, comprising basic industrial chemicals (including fertilizer), miscellaneous chemical products, pharmaceuticals, petroleum and coal products, and cement industries; and engineering industries, comprising metal products, machinery, electrical machinery and equipment, transport equipment, and automobile and cycle industries. For estimation purposes, cross-sectional and time-series data have been pooled within each of the three groups. We thus assume a high degree of similarity of technologies within each of the three industry groups. A full set of three-digit industry dummies has been included in the demand equations to isolate industry shift effects.

Since the industry-level variable are totals over a varying number of firms in each industry, all dependent and independent variables, with the exception of the output share of the public sector and the equity share of the foreign sector, have been divided by the number of firms in the industry. This removes a potential source of heteroscedasticity in the residuals of the demand equations.

The systems in equation (2) have been estimated jointly by the iterative seemingly-unrelated regressions (ITSUR) (Zellner, 1963) method to take account of error interdependence and symmetry restrictions across equations. ITSUR provides consistent and efficient estimates for the demand system parameters. Note that since all the prices have been divided by the price of fuel (to impose homogeneity of degree zero in prices), the symmetry restrictions in effect apply only to the production and non-production labor demand equations.

5. Results

The regression results for the light, chemical, and engineering industries are presented in Appendix Tables A1-A3, respectively. The own and cross price elasticities of input demand, being more easily interpretable, are calculated and shown in Table 4. The elasticities of input demand with respect to output and the fixed factors of production are shown in Table 5 for the three industry groups. Below we summarize the main findings from these tables.

The empirical results are generally consistent with the predictions of production theory. For instance, out of a total of nine own-price elasticities estimated (three for each industry group), only one has the wrong sign (and even this is not significant). Six of the nine own-price elasticities are significantly less than zero, as the cost function model predicts. Further, with the exception of domestic patenting, all inputs have positive output elasticities, as would be expected of non-inferior inputs.

Patenting by nationals does not appear to be significantly responsive to prices, except in the case of light industries. Even in these industries, the price elasticities, although statistically significant, are numerically small. They suggest that local inventive activity is complementary to both production and nonproduction labor but substitutable for fuel. On the other hand, foreign technology appears to be a strong substitute for production labor and fuel in the light and engineering industries, but is not significantly related to nonproduction labor. The results thus suggest that the foreign technology being used in India, at least in the light and engineering industries, is of the (production) labor- and fuel-saving type.

International inventive activity, as proxied by the cumulative number of patents granted in the United States over the previous five-year period, has very strong positive effects on inventive activity within India. For instance, the elasticity of Indian patenting with respect to U.S. patenting is greater than one in the light industries and greater than two in the chemical industries. (The elasticity is not significantly different from zero in the engineering industries.) These results merit further discussion.

To the extent that patents provide intellectual property protection for a patent recipient, they block other firms from 'reinventing' or patenting the same invention. However, a patent also discloses important information about an invention to the public. Since the protection provided by patents is rarely complete, other firms can use this public information to 'invent' a parallel product/process and patent it. The extent to which a patent granted to one firm retards or promotes patenting by other firms then depends on which of the two effects -- blocking or disclosure -- dominates. Exactly the same effects operate at the international level. To the extent that American (and other) firms patent their inventions in the U.S. to block Indian (and other) firms from reinventing the same product or process, there is a (negative) blocking effect of U.S. patenting on Indian patenting. However, U.S. patenting also can have a (positive) disclosure effect whereby Indian firms can learn of an invention which they would otherwise not have known about, modify it, and patent an adapted version

Table 4. Own- and cross-price elasticities of input demand: Indian industries, 1960-70.[a, b, c] (t-statistics in parentheses)

Industry Group	With Respect to:	Elasticity of Production Labor	Non-Production Labor	Fuel	Technology Imports	Domestic Patenting
Light	W_P	-2.652 (-10.3)	-0.277 (-6.7)	1.536 (2.3)	1.396 (2.0)	-0.003 (-5.1)
	W_N	-0.727 (-6.7)	-0.390 (-5.7)	1.562 (5.5)	-0.443 (-1.5)	-0.001 (-4.4)
	P_F	-0.512 (-1.6)	0.039 (0.2)	-2.449 (-3.1)	2.919 (3.5)	0.002 (2.9)
Chemical	W_P	-0.893 (-5.7)	0.093 (0.9)	0.803 (3.8)	-0.004 (-1.6)	0.001 (0.6)
	W_N	0.110 (0.9)	-0.344 (-2.3)	0.237 (1.0)	-0.004 (-1.2)	0.001 (0.9)
	P_F	-0.330 (-1.1)	0.486 (2.5)	-0.155 (-0.4)	-0.000 (-0.0)	-0.001 (-0.4)
Engineering	W_P	-0.196 (-1.2)	-0.250 (-2.6)	0.057 (0.4)	0.389 (4.1)	-0.001 (-0.8)
	W_N	-0.143 (-2.6)	-3.887 (-10.6)	3.914 (7.4)	0.115 (0.3)	0.001 (0.2)
	P_F	-0.948 (-2.5)	0.064 (0.3)	0.509 (1.4)	0.375 (1.7)	0.001 (0.4)

Notes:

[a]Elasticities have been evaluated at the sample means of each industry group. The coefficients used in calculating the elasticities are reported in Appendix Tables A1-A3.

[b]Since all prices have been normalized by the fuel price in the estimated equation, no symmetry has been imposed between the fuel price effects on labor demand and the wage effects on fuel demand. As such, the signs of these effects may not be the same.

[c]The t-statistics calculated are only approximate since they only take account of the variance of the estimated coefficients and not of the predicted values of the random variables.

Table 5. Output and fixed factor elasticities of input demand: Indian industries, 1960-70.[a]

Industry Group	With Respect to:	Elasticity of Production Labor	Non-Production Labor	Fuel	Technology Imports	Domestic Patenting
Light	USPATNTS	-0.327*	-0.119*	0.218*	1.308*	1.128*
	FORSHARE[b]	-0.751*	0.205	-1.404*	0.578	0.159
	PUBSHARE[b]	0.330*	0.010	0.317*	-0.258	0.011
	FIXEDCAP	0.658*	0.617*	0.830*	-0.248	-0.013
	OUTPUT	0.297*	0.242*	0.453*	0.114	-0.108*
	TIME[c]	-0.092*	-0.015*	-0.056*	0.181*	0.101*
Chemical	USPATNTS	-0.012	0.099	-0.065	1.107*	2.120*
	FORSHARE[b]	-0.014*	-0.013	0.006	-0.011	-0.120*
	PUBSHARE[b]	0.007	0.007	0.050	0.026	0.216*
	FIXEDCAP	0.947*	1.075*	0.664*	-0.157	0.464
	OUTPUT	0.260*	0.021	0.622*	0.025	-0.809*
	TIME[c]	-0.105*	-0.073*	-0.068*	0.167	0.111*
Engineering	USPATNTS	-0.059	0.055	0.051	0.557*	0.196
	FORSHARE[b]	0.105*	0.111	0.101	0.095	0.027
	PUBSHARE[b]	-0.030*	-0.039*	-0.020*	0.001	0.030
	FIXEDCAP	0.785*	0.123	0.360	-0.356	-0.655*
	OUTPUT	0.169*	0.553	0.827*	0.391*	0.499
	TIME[c]	-0.040*	-0.338*	-0.046	-0.038	-0.114*

Notes:

[a] Elasticities have been evaluated at the sample means of each industry group using the coefficients reported in Appendix Tables A1-A3.

[b] The figures in these rows are partial elasticities. That is, they show the per cent change in the dependent variable due to a one percentage point increase in the independent variable.

[c] The figures in this row show the trend rate of change of the dependent variable (per cent per annum).

*Significant at the 0.10 level of significance or lower. The tests of significance are only approximate since the t-statistics only take account of the variance of the estimated coefficients and not of the predicted values of the random variables.

in India. (Disclosure, while required in patent documents, is often provided by the exposure of the product to the market.) By increasing the pool of knowledge from which to learn, imitate and adapt, international inventions can stimulate Indian inventive activity. The net effect of international inventive activity on Indian inventive activity will thus depend on the relative magnitudes of the blocking and disclosure effects. Our empirical results suggest that the disclosure effect significantly dominates the blocking effect in the Indian case. The fact that the elasticity of Indian patenting with respect to U.S. patenting is significantly larger in the chemical sector than in the light or engineering sectors probably reflects the lower appropriability of inventions (from the point of view of the inventor firm) in the chemical/pharmaceuticals industries. It is well known that infringement or side-stepping of patents is much easier in these than in other industries.

The impact of international inventive activity on the demand for foreign technology will indicate the extent to which local inventive activity and foreign technology are substitutes or complements in Indian manufacturing. The econometric results indicate a strong and pervasive positive effect of international inventions on the demand for foreign technology across all industry groups. In the case of light and chemical industries, the elasticity of demand for foreign technology with respect to international inventions is approximately one, while it is about 0.6 in the case of engineering industries. These results suggest that foreign technology acquisition and local inventive activity are complementary to each other in Indian manufacturing. This has important implications for government policies on import of foreign technology and know-how.

Since we have used expenditure, not quantity, as our dependent variable, the elasticity we have estimated may be a hybrid of the true demand elasticity and the elasticity of the "price" per unit of foreign technology with respect to international inventions. In this case, we may not be able to interpret the estimated elasticity as a demand elasticity. However, since an increase in international inventions is likely to lower the "price" of foreign technology to Indian firms, given competitive international technology markets, the true elasticity of demand for foreign technology with respect to international inventions is likely to be even greater than the one (expenditure elasticity) estimated here. Our finding that foreign technology acquisition and local inventive activity are complementary thus holds.

Foreign and state ownership are not associated significantly with the demand for domestic patenting or foreign technology, except in the case of the chemical industries where domestic patenting is related inversely to foreign ownership and positively to state ownership. The negative foreign ownership effect may reflect the propensity of subsidiaries of multinational drug companies in India to use innovations developed by their parent companies, often at great cost, and avoid local R&D in India.[3] However, since our results do not show a positive association between acquisition of foreign technology and the extent of foreign ownership, it is not clear how much credence can be placed in this explanation.

The positive state ownership effect on domestic patenting in the chemical sector is most likely the result of two large state-owned corporations -- Indian Drugs and Pharmaceuticals and Hindustan Antibiotics -- being included in this industry group. Both corporations were set up in the late 1950s to reduce India's dependence on foreign technology and on multinational drug companies, and therefore, had a mandate to engage in substantial R&D activity.

Finally, the relationship between inventive activity and firm size is of interest, since it has produced a large literature in the context of developed countries. The general evidence from these countries is that, with the possible exception of the chemical industry, the <u>intensity</u> of research effort (i.e., research effort deflated by a measure of firm size) does <u>not</u> increase with firm size. This implies that the elasticity of research effort with respect to firm size is positive but less than unity (Worley 1961, Hamberg 1966, Mueller 1967, Mansfield 1968). In some cases, research intensity is found to initially increase, but then decrease, with firm size (again with the possible exception of the chemical industry) (Scherer 1965a, Grabowski 1968). Most of the above studies have used R&D expenditure as percentage of sales or R&D employees as percentage of total employees as their dependent variables. Studies that have used patents as a measure of inventive activity have generally found the relationship between the absolute number of patents granted and firm size to be of an inverted U-shape type (Scherer 1965b, Johannisson and Lindstrom 1971). This suggests that "....beyond some magnitude, size does not appear especially conducive to either innovational effort or output in either this country or in European countries where studies have been conducted.... It seems noteworthy that the chemical industry is cited as an exception both for the U.S. and abroad" (Kamien and Schwartz, 1975: 19).

In this paper, both fixed capital stock and output provide a measure of firm size. Even the absolute level of domestic patenting is observed to decline with output in the light and chemical industries and with fixed capital stock in the engineering industries. These results imply that the intensity of patenting (i.e., patenting per unit of firm size) declines very sharply with firm size in Indian manufacturing. The decline is sharpest in the chemical industries, followed by the engineering and the light industries (in that order). On the other hand, the demand for foreign technology does not appear to be significantly related to firm size, except in the engineering industries where it increases with output. However, since this elasticity is less than one, the intensity of foreign technology use still declines with output.

Several other interesting findings relating to the demand for labor and fuel emerge from the empirical analysis. However, a detailed discussion of these results is beyond the scope of this paper.

6. Conclusion

In this paper, we have studied the determinants of local inventive activity and foreign technology use in the manufacturing sector of India, using a cost function framework and industry-level data for the period 1960-70. International inventive activity, proxied by the cumulative number of patents granted in the United States during the preceding five years, emerges as the strongest determinant of local inventive activity, proxied by the number of patents granted to nationals in India. In fact the elasticity of domestic patenting with respect to U.S. patenting is greater than one in the light industries and greater than two in the chemicals industries. These results indicate a strong diffusion of inventions from the United States to India, and suggest that the disclosure effect of U.S. patenting dominates over the blocking effect. At the same time, the demand for foreign technology in Indian manufacturing also appears to be strongly stimulated by international inventions.

The finding that the flow of international technology stimulates Indian invention should lead to a possible reevaluation of Indian patent policy. India undertook steps to weaken its patent system in 1970 in part because it sought to reduce foreign influence and technological dependency. Our results, which cover the period before this policy was implemented, however, suggest that the legal and institutional setting in India during the 1960s was quite conducive to enabling both local inventive activity and foreign technology purchase to benefit from international invention. Indeed, a weak patent policy may well have stifled the stimulus that foreign invention provides in enabling both more effective technology purchase from abroad and domestic adaptive R&D. Further study, using post-1970 data, is required to determine whether this indeed happened. Further study is also required to determine the effects of general industrial policies, such as trade protection and capacity licensing, on the demand for foreign technology and local inventive activity.

The finding that foreign technology use and local inventive activity are complementary to each other also underscores the importance of a liberal technology import policy. The Indian government has been pragmatic in this respect; it has adopted a fairly flexible posture toward foreign technical collaborations, and has encouraged foreign technology purchase by Indian firms.

Notes

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[1]Expenditures are in current terms. Inflation rates in India were low over the period -- less than 4 per cent per year.

[2]See Griliches (1987) for a survey of the literature which uses patent statistics as economic indicatos.

[3]Our colleague, T.N. Srivivasan points out that in addition to capacity licensing, the Indian government controlled the allocation of some imported inputs. We acknowledge that if this rationing of inputs was substantial, our cost function treatment is not appropriate. We believe, however, that it was not so severe as to call for a rationing or fixed factor approach to the inputs that we consider to be variable. It primarily affected capital stocks which we treat as fixed in the model.

[4]The "price" of technology purchased abroad is also variable and

and constitutes a type of annual rental payment for a service flow.

[5]We acknowledge that we cannot argue that technology purchases and own R&D do not have some investment component. We are faced with the choice of treating these activities in the variable factor framework as in a quasi-fixed factor investment framework. The latter framework is not well suited to addressing the joint choice of technology purchase and own R&D.

[6]T.N. Srinivasan notes that the Indian government has placed some restrictions on technology inports into India. These will affect technology purchases and own R&D. Our demand function for these activities have to be interpreted subject to these restrictions. We do not have information on the extent of these restrictions or on their changes over time. The time trends in the equations and the division of firms into 3 broad industry groups partially addresses the problem presented by restrictions on technology imports.

[7]The weighted R^2's for cash system indicates a high proportion of variance explained by the estimates.

[8]We have not attempted to specify the lag structure behind this affect. We have imposed a 5 year lag on the international patent stock. Indian R&D response may also have a lag. It should also be noted that the marketing of a new product based on these patents will also provide disclosure effects.

[9] In a survey of U.S.-based multinational corporations, Mansfield, et.al. (1979) found that 29-34 per cent of the profit returns from the R&D projects of these corporations on average came from overseas exploitation. The corporations estimated that their R&D budgets would be reduced by 12-15 per cent if they were unable to pass innovations on to their foreign subsidiaries.

APPENDIX

Data Sources

1 Data on technology imports and on foreign equity share were obtained from the Reserve Bank of India, Foreign Collaboration in Indian Industry: Survey Report, Bombay: Reserve Bank of India, 1968 for the period 1960-61 to 1963-64, and from the Reserve Bank of India, Foreign Collaboration in Indian Industry: Second Survey Report 1974, Bombay: Reserve Bank of India, 1974, for the period 1964-65 to 1969-70.

2 Data on the fuel price index was obtained from India, Planning Commission, Statistics and Surveys Division, Basic Statistics Relating to the Indian Economy 1950-51 to 1970-71, New Delhi, 1972.

3 Data on the public sector in production was obtained from the Commerce Yearbook of the Public Sector, Bombay: Commerce Publications, 1974.

4 Data on number of patents granted in the U.S. were obtained, tabulated by industry, directly from the U.S. Patent Office.

5 Data on patenting by nationals in India were hand-tabulated directly from actual patent applications on file at the New Delhi office of the Indian Patent Office. Data on approximately 42,000 patents granted through 1979 were collected. A relatively complete concordance of the Indian patent classification with the Indian industrial classification was also possible. Only 5,845 of the 41,588 patents in the basic file were in classes where assignments to industries proved unreasonable.

Appendix Table A1. ITSUR estimates of input demand equations: light industries, India, 1960-70.

Independent Variables	Production Labor	Non-production Labor	Fuel	Technology Imports	Domestic Patenting
W_P/P_F	-409,347,106	-5,576	-128,956	-6,329,136	16,708
	(-9.8)	(-6.3)	(-1.5)	(-1.2)	(0.5)
W_N/P_F	-5,576	-0.39	1.27	474	4.73
	(-6.3)	(-5.4)	(0.1)	(0.9)	(1.6)
USPATNTS	-2,099	-0.04	2.35	409	4.26
	(-4.9)	(-4.2)	(2.8)	(8.2)	(14.2)
USPATNTS	12,865	0.28	-15.26	-2,524	-17.05
Squared ($X10^4$)	(3.0)	(3.2)	(-1.8)	(-5.1)	(-5.7)
FORSHARE	4,168,019	-65.66	14,235	-213,083	-347
	(1.9)	(-1.4)	(3.3)	(-0.8)	(-0.2)
FORSHARE	-87,365	1.35	-295	4,335	7.76
Squared	(-1.9)	(1.4)	(-3.3)	(0.8)	(0.2)
PUBSHARE	1,476,072	-12.36	3,945	-79,567	-73.39
	(2.4)	(-0.9)	(3.2)	(-1.1)	(-0.2)
PUBSHARE	-168,779	1.71	-484	9,582	10.58
Squared	(-2.2)	(1.0)	(-3.2)	(1.7)	(0.2)
FIXEDCAP	1,818	0.16	11.21	-68.57	-0.31
($X10^4$)	(1.5)	(6.2)	(4.5)	(-0.5)	(-0.4)
FIXEDCAP	132,064	1.75	-89.32	-678	12.87
Squared ($X10^{12}$)	(5.7)	(3.5)	(-1.9)	(-0.2)	(0.8)
OUTPUT	396	0.02	1.00	7.43	-0.09
($X10^4$)	(6.1)	(11.2)	(7.8)	(1.0)	(-2.0)
TIME	-62,937	-0.48	-63.95	6,060	43.40
	(-4.8)	(-1.7)	(-2.4)	(3.9)	(4.6)

Notes:

1) All five equations have been estimated jointly by the iterative seemingly-unrelated regressions method. Symmetry restrictions across the first two equations, as well as zero homogeneity in prices for each equation, have been imposed. Asymptotic t-statistics are in parentheses.

2) A full set of three-digit industry dummies as well as an intercept were included in each equation. The coefficients on these terms have not been reported in the table due to space limitations.

3) For a description of the variables, see Table 3.

Appendix Table A2. ITSUR estimates of input demand equations: chemical industries, India, 1960-70.

Independent Variables	Production Labor	Non-Production Labor	Fuel	Technology Imports	Domestic Patenting
W_P/P_F	-116,490,552 (-5.1)	1,492 (0.8)	-513,440 (-1.0)	1,202,555 (0.1)	1,386 (0.1)
W_N/P_F	1,492 (0.8)	-0.58 (-2.1)	93.18 (2.3)	-1,105 (-1.3)	-0.92 (-0.8)
USPATNTS	201 (0.6)	0.04 (0.8)	-2.62 (-0.4)	231 (1.6)	1.35 (6.7)
USPATNTS Squared ($X10^4$)	-638 (-0.6)	-0.13 (-0.9)	0.43 (0.0)	-570 (-1.4)	-2.76 (-5.0)
FORSHARE	-37,879 (-1.5)	-3.87 (-1.1)	-1.38 (-0.0)	-3,414 (-0.3)	-57.90 (-4.0)
FORSHARE Squared	813 (1.3)	0.09 (1.0)	2.77 (0.2)	101 (0.4)	1.33 (3.7)
PUBSHARE	23,905 (1.5)	1.48 (0.7)	409 (1.3)	4,327 (0.7)	22.53 (2.5)
PUBSHARE Squared	-524 (-1.5)	-0.02 (-0.5)	-7.56 (-1.1)	-89.81 (-0.7)	-0.52 (-2.7)
FIXEDCAP ($X10^4$)	681 (9.1)	0.08 (7.3)	5.54 (3.8)	3.72 (0.1)	0.05 (1.3)
FIXEDCAP Squared ($X10^{12}$)	-390 (-4.4)	-0.03 (-2.8)	-2.91 (-1.7)	-21.39 (-0.6)	-0.03 (-0.6)
OUTPUT ($X10^4$)	112 (2.9)	0.00 (0.2)	3.19 (4.1)	0.57 (0.0)	-0.06 (-2.6)
TIME	-115,240 (-7.0)	-8.24 (-3.6)	-879 (-2.7)	9,595 (1.5)	20.06 (2.2)

Notes:

1) All five equations have been estimated jointly by the iterative seemingly-unrelated regressions method. Symmetry restrictions across equations (1) and (2), as well as zero homogeneity in prices for each equation, have been imposed. Asymptotic t-statistics are in parentheses.

2) A full set of three-digit industry dummies as well as an intercept were included in each equation. The coefficients on these terms have not been reported in the table due to space limitations.

3) For a description of the variables, see Table 3.

Appendix Table A3. ITSUR estimates of input demand equations: engineering industries, India, 1960-70.

Independent Variables	Production Labor	Non-Production Labor	Fuel	Technology Imports	Domestic Patenting
W_P/P_F	-23,671,437 (-1.1)	-4,913 (-2.4)	-442,899 (-2.4)	68,330,770 (1.3)	17,727 (0.9)
W_N/P_F	-4,913 (2.4)	-21.79 (-10.0)	4.83 (0.3)	-13,359 (-2.6)	-2.29 (-1.3)
USPATNTS	-35.36 (-0.7)	0.01 (0.2)	0.15 (0.4)	396 (3.2)	0.01 (0.02)
USPATNTS Squared ($X10^4$)	-5.42 (-0.1)	-0.01 (-0.2)	-0.11 (-0.3)	-57.19 (-0.6)	0.07 (2.1)
FORSHARE	1,688,754 (3.8)	142 (0.3)	6,290 (1.6)	778,779 (0.7)	146 (0.4)
FORSHARE Squared	-34,416 (-3.9)	-2.46 (-0.3)	-128 (-1.7)	-14,822 (-0.6)	-3.04 (-0.4)
PUBSHARE	-48,569 (-6.9)	-14.82 (-1.8)	-100 (-1.6)	2,243 (0.1)	9.65 (1.5)
PUBSHARE Squared	618.63 (8.3)	0.14 (1.6)	0.88 (1.4)	-24.32 (-0.1)	-0.08 (-1.3)
FIXEDCAP ($X10^4$)	1,853 (7.7)	0.06 (0.2)	3.21 (1.5)	-938 (-1.5)	-0.39 (-1.8)
FIXEDCAP Squared ($X10^{12}$)	-2,876 (-6.0)	0.12 (0.2)	-4.27 (-1.0)	1,683 (1.4)	0.52 (1.2)
OUTPUT ($X10^4$)	235 (1.8)	0.22 (1.5)	4.44 (3.9)	595 (1.8)	0.18 (1.5)
TIME	-34,721 (-2.1)	-85.39 (-4.4)	-153 (-1.1)	-36,048 (-0.8)	-25.10 (-1.7)

Notes:

1) All five equations have been estimated jointly by the iterative seemingly-unrelated regressions method. Symmetry restrictions across equations (1) and (2), as well as zero homogeneity in prices for each equation, have been imposed. Asymptotic t-statistics are in parentheses.

2) A full set of three-digit industry dummies as well as an intercept were included in each equation. The coefficients on these terms have not been reported in the table due to space limitations.

3) For a description of the variables, see Table 3.

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