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PRIVATE INVENTIVE ACTIVITY IN INDIAN MANUFACTURING: ITS EXTENT AND DETERMINANTS

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1. Introduction

While there is a large literature on 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. Very few empirical studies have attempted to analyze innovation in the manufacturing sectors of less-developed countries, although it is quite possibly an important factor in productivity growth for these countries. While it is true that inventive activity at the level of the firm is much lower in LDCs than in developed countries and that a large part of this activity is 'blue-collar' or informal R&D on which data are difficult to obtain, there is nevertheless evidence -- at least for the larger LDCs like Brazil, India and Korea -- of not insignificant R&D activity and patenting in some enterprises and industries (Evenson 1984).

This paper attempts to describe the extent of inventive activity in the manufacturing sector of a large LDC, viz., India. India is an LDC for which expenditure on and number of employees involved in research and development activities are not inconsequential (see section 2 below). In addition, we survey the econometric literature on the determinants of private inventive activity in India.

2. R&D Activity in Indian Manufacturing

The amount of expenditure on research and development activities in a less-developed country, such as India, is obviously going to be quite low when compared to the more-developed countries, such as the United States. The nature of Indian R&D activity is also going to be quite different from that of U.S. R&D activity. In particular, most R&D undertaken by Indian firms is *adaptive*, as opposed to basic, R&D.

Table 1 shows the amount of expenditure on R&D and related science and technology (S&T) activities as a percentage of GNP for 20 countries in 1973-74. India spent only .4 per cent of its GNP on R&D/S&T, as compared to 2.8 per cent by the United States and 4.2 per cent by the Soviet Union. However, India allocated a larger proportion of its GNP to R&D and science expenditures than most other less-developed countries, including the more industrialized of the LDCs, such as Argentina and Mexico.

The distribution of Indian R&D expenditures across public and private sectors is brought out in Table 2. Two facts stand out from this table. *First*, the percentage of GNP spent on *all* R&D and related scientific activities has been increasing steadily, from .23 per cent in 1958-59 to .47 in 1970-71 to .65 in 1976-77. *Second*, most of the expenditures on R&D and science in India are undertaken by the public sector. Only about 10-15 per cent of the total national expenditure on R&D and scientific activities is spent by the private sector. In this paper, we concentrate on innovative activities by the private sector, since most of the studies on the utilization of public research have shown that "... the extent of government R&D utilized by industry is very small, and it is becoming increasingly clear that for any significant improvement in the technological capabilities of Indian firms, R&D will need to be done mainly within the firm" (Alam 1985: 2076).

Some of the longest time-series information on the R&D activities of Indian firms comes from the Reserve Bank of India's *Foreign Collaboration Surveys*, which have covered the period

Table 1
International Comparisons of R&D Intensity, 1973-4

Country	R&D Expenditure as % of GNP
Argentina	.2
Belgium	1.3
Canada	1.3
Czechoslovakia	3.6
France	2.0
West Germany	1.8
Ghana	.2
Iran	.3
India	.4
Italy	.9
Japan	1.8
South Korea	.5
Mexico	.1
Netherlands	2.2
Pakistan	.1
Sweden	1.2
U.K.	2.4
U.S.A.	2.8
U.S.S.R.	4.2
Yugoslavia	1.0

Source: National Committee on Science and Technology, *Research and Development Statistics*, May 1975, p. 15

Table 2

Sectorwise Expenditure on R&D and Science & Technology, India, 1958-9 to 1976-7

Variable	1958-9	1965-6	1968-9	1969-70	1970-1	1971-2	1972-3	1973-4	1974-5	1975-6	1976-7
Public Expenditure on R&D as % of GNP	0.18	0.29	0.48	0.31	0.34	0.35	0.40	0.35	0.40	0.48	0.50
Private Sector Exp. on R&D as % of GNP	0.00	0.01	0.05	0.04	0.04	0.04	0.05	0.06	0.06	0.07	0.07
Total R&D Exp. as % of GNP	0.18	0.30	0.53	0.35	0.38	0.39	0.45	0.40	0.46	0.55	0.65
Public Expenditure on Related Science & Technology Activities as % of GNP	0.05	0.07	0.12	0.09	0.09	0.08	0.09	0.07	0.05	0.06	0.07
Total Public Expenditure on R&D and S&T Activities as % of GNP	0.23	0.36	0.60	0.40	0.43	0.43	0.49	0.42	0.45	0.55	0.65
Total Public and Private Expenditure on R&D and S&T Activities as % of GNP	0.23	0.37	0.64	0.43	0.47	0.47	0.54	0.47	0.51	0.61	0.72

Source: Department of Science and Technology, Government of India, Research and Development Statistics, 1976-77.

from 1964-65 to 1980-81.[1] These surveys have typically covered only firms that engage in some foreign collaboration, and therefore exclude firms that may undertake R&D but not engage in any foreign technical or equity collaborations. However, the number of such firms is likely to be very small, and the figures obtained from the *Surveys* and reported in Table 3 may be taken as representing accurately the extent of R&D activity in the (private) Indian corporate sector. Table 3 indicates that, compared to the more-developed countries like the United States, the extent of R&D activity undertaken at the firm level in India is very limited. In most industries less than one per cent of sales is devoted to R&D. This contrasts with the 2-3 per cent of sales that is often devoted to R&D in many manufacturing industries in the United States.

Table 3 further indicates a great deal of inter-industry variation in the intensity of R&D. Over time the pharmaceuticals industry has had the greatest intensity of R&D, followed by several engineering industries, such as transport equipment manufacture, electricity machinery and apparatus, and machinery and machine tools (especially during the latter time periods). The consumer goods industries, such as textile products and food and beverages, have consistently had low R&D intensities.

Over the 15-year period covered by the data in Table 3, the average intensity of R&D across all manufacturing industries has been remarkably stable, at around .5 per cent of sales. However, this stability masks a substantial fall in the extent of R&D activity in the pharmaceuticals and drugs industry (from about 1.62 per cent of sales in 1964-70 to 1.04 per cent in 1980-81) and an increase in the machinery and machine tools (from .14 per cent to .51 per cent of sales) and the metals and metal products industries (from .07 per cent to .25 per cent of sales).

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[1]The Department of Science and Technology, Government of India, also reports industry-specific data on R&D expenditures in its *Research and Development Statistics* series. However, this series began only in 1972-73. In addition, the Economic and Scientific Research Foundation in New Delhi collected a great deal of information relating to imports, exports, foreign collaborations and R&D activities in its survey of the largest 300 companies in India in 1979. However, the survey only covered the period 1965-66 to 1970-71. Neither of the two surveys contradicts the evidence presented here from the Reserve Bank of India's *Foreign Collaboration Surveys*.

Table 3

Research and Development Expenditure in Indian Private-Sector Manufacturing: 1964-65 to 1980-81

Industry	R&D Expenditure (on Current Account) as % of Sales		
	Avg.of 1964-5 to 1969-70	1977-78	1980-81
Food and Beverages	.21	.48	.17
Textile Products	.09	.31	.10
Transport Equipment	.81	.63	.83
Machinery & Machine Tools	.14	.55	.51
Metals & Metal Products	.07	.25	.25
Electrical Machinery & Apparatus	.73	.75	.56
Chemicals & Chemical Products	1.04	.59	.61
- Basic industrial	.67	.42	.43
- Drugs & Pharmaceuticals	1.62	.94	1.04
- Others	.48	.61	.58
Rubber Products	.11	.25	.19
Miscellaneous	.23	.30	.23
All Manufacturing	.46	.53	.51

Source: Reserve Bank of India, 1974, p.139 and Reserve Bank of India (1985), p.180.

Table 4

Size of R&D Labor Force in Indian Industry: 1969-70 and 1980-81

Ownership Type of Enterprise	Number of Employees in R&D Divisions as % of Total Number of Employees	
	1969-70	1980-81
Subsidiaries of Foreign Enterprises	2.5	2.5
Minority Foreign Capital Companies	2.4	1.7
Indigenously-owned Companies	1.4	1.6
All Private-Sector Companies	2.1	1.8
Public-Sector Companies	4.0	1.4

Source: Reserve Bank of India, 1974, p.141 and Reserve Bank of India, 1985, p.181.

The drop in R&D intensity in the pharmaceuticals sector was most likely the result of a change in the patent law in 1970. In 1970 a new and weak patent law was implemented, which significantly reduced the life of patents and altogether did away with product (as opposed to process) patents. It is widely believed that this legislation slowed down the rate of patenting activity in most industries (Bagchi e al., 1984). The patent data we examine below suggest that the rate of patenting in the pharmaceuticals industry dropped very sharply in the period immediately following the new patent legislation. It is interesting to note that the data on R&D intensities confirms this trend.

The *Foreign Collaboration Surveys* also report data on R&D personnel. Unfortunately, these data are not broken down by industry. Table 4 shows the number of R&D personnel as a percentage of the total number of employees for different ownership groups of firms over the period 1969-70 to 1980-81. With the exception of the public sector (where there was a large decline in the proportion of R&D workers), the share of R&D employees in the total work force of manufacturing firms was fairly stable over the period.

3. Patenting in India

Another indicator of inventive activity -- especially of the intermediate output of inventive activity -- is the number of patents granted to Indian nationals.[2] We have collected data on some 42,000 patents granted in India since 1954 either from actual patent documents on file at the New Delhi office of the Indian Patent Office (in the case of 30,000 patents granted between 1954 and 1973) or from *The Gazette of India* (in the case of 12,000 patents granted between 1973 and 1979). A relatively complete concordance of the Indian patent class with Indian industrial data was constructed. Only 5,845 of the 41,588 patents in the basic file were in

[2]See Griliches (1981, 1987) for a discussion on using patent statistics as indicators of inventive activity.

classes where assignments to industries at the five-digit level proved unreasonable.

Table 5 provides a summary of the patent data for 4-year periods between 1954 and 1978. The data are organized according to industrial application. The table also reports the percentage of patents granted to nationals in 1975-78 (column marked "Percent India") and the intensity of patenting (viz., number of patents granted per million rupees of sales) for the entire 1954-78 period.

It is readily apparent that the share of Indian national patenting varies by industries, as does the patenting intensity. It is also clear that patenting by foreigners increased for the first 3-4 periods and declined for the last 2-3 periods in most industries. The electrical equipment industries are an exception. Patenting by Indian nationals has increased over all periods in many industries and the proportion of patents granted to Indian nationals has risen in all industries. What is interesting to note is the sharp discontinuity in the rate of growth of patenting around 1970. In several industries, patenting fell sharply, or did not continue to grow at earlier rates, during the period immediately following 1970. As we mentioned earlier, a new patent law came into effect in 1970 which generally reduced the protection offered to patents. However, Table 5 suggests that patenting activity may have picked up again in the post-1975 period, perhaps after firms were able to adapt to the new proprietary rights legislation.

Table 6 reports a tabulation of the origin (e.g., whether small or large firms, universities, the Indian Council of Scientific Research [CSIR], etc.) of patents for major industry groups. These data show the rather substantial increase in the importance of patenting by all types of Indian institutions. The importance of individuals and small firms in patenting is particularly noteworthy since it indicates that inventions meeting standards of patentability are not the province of large corporations.

For the period 1973-79, data were obtained on the number of claims made on patents as well as the cessation of patents. India has a renewal system for patents with many patents being allowed to expire. The cessation and claims data are possible indicators of patent

Table 5

Number of Patents Granted to Nationals in India, by Industry and Year, 1954-57 to 1975-78

Industry	1954-57	1958-61	1962-66	1967-70	1971-74	1975-78
Food Processing	26	69	123	132	54	65
Textile Manufacture	52	76	92	86	59	75
Jute Manufacture	1	2	4	3	3	0
Textile Products	4	6	9	19	2	7
Wood Products	4	5	7	8	9	16
Paper & Printing	21	28	54	50	25	46
Leather	22	13	18	23	12	9
Rubber & Plastics	18	33	55	59	35	53
Chemicals	46	92	137	251	127	183
Non-Metallic Mineral Products	25	54	72	85	58	108
Basic Metals	1	2	12	7	18	38
Metal Products	-	-	-	-	45	124
Machinery (excl. Heavy Mach. & Prime Movers)	10	37	48	74	34	70
Electrical Equipment*	4	26	13	16	61	156
Transport Equipment (excl. Aircraft)	8	36	34	47	20	44

Notes: *Excluding Communication Equipment, Storage Batteries, and Computing Devices.

Table 6 : Distribution of Patents by Origin

	Light Industries		Chemical Industries		Engineering Industries	
	1954-57	1975-78	1954-57	1975-78	1954-57	1975-78
Indian	15.70	31.63	7.11	23.15	7.44	27.22
Firms - Large	1.48	4.50	.80	3.80	.96	2.39
Firms - Small	2.00	5.77	1.20	3.63	1.44	4.05
CSIR	2.53	2.42	1.20	5.88	.72	5.20
University	1.37	4.62	.46	3.57	.24	1.89
Individuals	8.32	14.32	3.45	6.57	4.08	13.69
Foreign	84.30	68.37	92.89	76.55	92.96	72.78
Great Britain	25.82	10.97	21.05	8.29	32.61	12.99
France	3.27	3.81	3.59	4.44	5.52	3.55
West Germany	8.54	10.74	6.44	12.67	7.91	9.33
Switzerland	6.11	6.81	5.51	1.67	1.92	1.97
Italy	2.53	2.54	1.59	2.71	1.68	.58
Japan	3.58	3.12	1.13	3.46	2.16	2.24
U.S.	10.75	13.97	20.58	25.29	19.66	25.10
Other	20.82	16.40	32.20	18.03	21.10	20.10

Light industries included industry group 1, 2, 3, 4, 5, 6, 7, 8, 9 and 12

Chemical industries included group 10 and 11

Engineering industries included group 13, 14, 15, 16, 17

importance. Table 7 reports our data on the average number of claims per patent and the number of years patents were in force (i.e., the number of years from the date granted to the date of cessation). Across all manufacturing sectors, patents of Indian origin appear to have fewer claims and are in force for shorter periods than patents of foreign origin. Among the three industrial sectors, patents in the engineering industries generally have the shortest life and fewest number of claims. Among the different ownership categories, patents granted to the CSIR have the fewest number of claims, which confirms the casual empiricism that innovations developed by the government laboratories are rarely utilized
by the private manufacturing sector.

4. Determinants of Inventive Activity

If we do not know much about the true extent and nature of innovative activity being undertaken by manufacturing firms in India, we know even less about the *determinants* of firms' decisions to undertake formalized inventive activity, such as R&D. Very little empirical research has attempted to understand why some firms seek to 'produce' their own technology, while others simply purchase or license it from international suppliers.

A. Firm Size

A priori it would seem that, if there are minimum economies of size in establishing R&D units or there are substantial economies of scale in R&D expenditures, R&D expenditures will typically increase less-than-proportionately with firm size. In other words, research intensity will fall with firm size. The evidence from the United States and other developed countries generally confirms this expectation (Worley 1961, Hamberg 1966, Mueller 1967, Mansfield 1968). In some cases, research intensity is found to initially increase, but then decrease, with firm size

Table 7 : Patent Characteristics by Industry

Type of Patent	Number of Claims			Patent Life		
	Light Industry	Chemical Industry	Engineering Industry	Light Industry	Chemical Industry	Engineering Industry
Indian						
Large firms	9.24	9.11	6.35	7.31	7.00	6.41
Small firms	7.13	7.15	7.03	7.53	6.73	6.35
CSIR	5.32	5.54	5.16	7.21	6.96	6.12
University	7.28	6.47	5.92	6.61	6.05	5.95
Individuals	6.17	6.44	6.22	6.55	6.85	5.40
Foreign						
Great Britain	13.79	15.07	11.10	8.64	8.65	8.45
France	12.09	11.58	11.37	8.24	8.97	7.95
West Germany	9.87	9.53	10.99	8.91	8.00	8.25
Switzerland	10.98	10.70	10.29	9.21	8.83	9.50
Italy	6.85	10.63	11.52	9.76	9.80	6.72
Japan	6.46	7.92	7.70	9.66	9.70	10.55
U.S.	11.97	12.46	11.26	9.11	8.94	8.09
Other	10.28	10.56	8.80	8.26	8.60	7.55

(again with the possible exception of the chemicals industry) (Scherer 1965a, Grabowski 1968). Most of the above studies have used R&D expenditures or personnel as their dependent variable. 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 ..." (Kamien and Schwartz, 1975: 19).

Desai (1985) grouped 22 manufacturing industries in India into four classes based on their degree of concentration (proxied by the Herfindahl index) and product differentiation (which he found to be closely correlated with the coefficient of variation of firms' market shares).[3] Within each of these groups, he compared the size and market shares of firms doing some R&D to (i) those not doing any R&D but importing technology, (ii) those not doing any R&D and not importing any technology, and (iii) all firms. The results of his analysis are shown in Table 8. Controlling for market structure (viz., the degree of concentration and product differentiation), firms doing R&D are typically larger than those not doing R&D. Firms not doing R&D nor importing their technology tend to be the smallest firms in any group. The same results generally hold with market shares; firms doing R&D tend to command larger market shares than firms not doing R&D within any given market structure. *Prima facie* these results might suggest that the propensity to undertake R&D depends positively on firm size and market share. However, these results have to be interpreted with caution, since they do not indicate the direction of causality, being based, as they are, on simple cross-tabulations, nor allow for any nonlinearities in the innovation-size relationship.

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[3]The group with greater concentration includes the cars, scooters, and motor cycles industries (in the case of less product differentiation) and the tractor, boilers, metallurgical machinery, cement machinery, and commercial vehicles industries (with more product differentiation). The group with lower concentration includes the refrigerator, compressors, and bicycles industries (with less product differentiation) and the diesel engines, earthmoving equipment, machine tools, chemical machinery, electric pumps, cranes and hoists, sugar machinery, motors, transformers, and switchgear industries (with more product differentiation).

Table 8
Proportion of Firms doing R&D in Selected Industries Grouped by Market Structure: India, 1978-79

	More Concentrated		Less Concentrated	
	Homo-geneous	Differen-tiated	Homo-geneous	Differen-tiated
Number of firms	5	9	27	131
Herfindalh Index	.45	.50	.08	.09
Coefficient of Variation of firms' market shares	.96	1.71	.81	2.85
Four-firm concentration (%)	95	89	57	48
Market Shares (%)				
Firms doing some R&D	58	95	55	57
Firms not doing R&D but importing technology	32	3	25	9
Firms not doing R&D and not importing technology	10	2	20	34
Average sales per firm (Rs. million)				
Firms doing some R&D	279	609	288	84
Firms not doing R&D but importing technology	226	58	210	29
Firms not doing R&D and not importing technology	47	56	79	7
All Firms	104	191	115	10

Notes: The "More Concentrated - Homogenous" group includes the cars, scooters, and motor cycles industries; the "More Concentrated - Differentiated" group includes the tractor, boilers, metallurgical machinery, cement machinery, and commercial vehicles industries; the "Less Concentrated - Homogenous" group includes the refrigerator, compressors, and bicycles industries; and the "Less Concentrated - Differentiated" group includes the diesel engines, earthmoving equipment, machine tools, chemical machinery, electric pumps, cranes and hoists, sugar machinery, motors, transformers, and switchgear industries. See text for a more precise definition of the groups.

Source: Desai (1985), p. 2083.

In his analysis of the R&D intensities of 100 Indian engineering firms in 1978, Lall (1983) found a positive and significant effect of firm size (as proxied by sales turnover) on R&D intensity. This suggests that R&D expenditures, at least for Lall's sample of Indian engineering firms, increase more-than-proportionately with sales. Lall attributed his results to the fact that larger firms tend to be more diversified, more complex technologically, and can afford larger R&D investments.

A recent study by Siddharthan (1987), using 1983-84 data on 166 firms (both public and private, and from 6-7 different industries) registered as having R&D laboratories with the Government of India's Department of Science and Technology, comes up with somewhat different results. Siddharthan finds a very strong U-shaped relationship between R&D intensity and firm size (as measured by sales),[4] such that R&D intensity decreases with size till a size of Rs. 600 million in sales turnover and increases with size thereafter. These results are quite robust and hold for the pooled sample of firms as well as for separate subsamples by industry and by ownership (i.e., private or public). Siddharthan attributes his results on the nonlinearity of the R&D intensity-size relationship to the fact that "... the nature and type of R&D activity between large and small firms is different, and therefore not strictly comparable" (Siddharthan 1987: 21).

One problem with the Lall and Siddharthan studies is that they estimate an R&D-size relationship using only the sample of firms doing some R&D. The positive effect of size on research intensity estimated by Lall as well as the U-shaped relationship between research intensity and firm size estimated by Siddharthan are likely to be biased in view of the fact that firms not doing any R&D (which are excluded from both analyses) are generally much smaller on average than firms undertaking R&D. Inclusion of non-R&D firms would most likely reduce the positive relationship between size and research intensity that Lall obtains. It is not clear *a priori* in what direction Siddharthan's results would change if firms not doing R&D were included in his sample.

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[4]Lall did not include a quadratic in firm size in the R&D intensity equation he estimated.

The selection problem is resolved by studies that use industry-specific data, since industry data are aggregates over all firms -- not just those undertaking R&D. In his analysis of Indian industry-level data for 1978-79, Katrak (1985) found that the elasticity of average R&D expenditures per firm with respect to average firm size (in terms of sales per firm) was positive but less than one, implying that R&D intensity decreases with firm size. But, since a quadratic in average firm size was not explicitly included in the R&D equation, it is not clear whether the decrease in R&D intensity with respect to firm size levels off and turns upward for very large average firm sizes.

Deolalikar and Evenson (1989) also used Indian industry-level data over the period 1960-70 to analyze the determinants of inventive activity, but they proxied inventive activity by the average (per firm) number of patents granted to Indian nationals in India. Their approach differs from other approaches in that they embed the demand for inventive activity (and for foreign technology) within a cost-minimization framework. The resulting reduced-form input demand equations have as their arguments the wage rates of production and nonproduction labor, the price of fuel, average gross output per firm, and several fixed factors (including average fixed assets per firm), some of which proxy the 'price' of foreign technology and of inventive activity. In this analysis, both fixed assets and output per firm provide a measure of firm size. Deolalikar and Evenson found that even the *absolute* level of domestic patenting declines with output in the light and chemical industries and with fixed assets in the engineering industries, which implies that the *intensity* of patenting declines very sharply with firm size in Indian manufacturing. The authors allowed for possible nonlinearities in the relationship between patenting and fixed assets per firm, but the quadratics in fixed assets were generally not significant.

In a forthcoming study, Deolalikar and Roller (1989) also analyze the determinants of patenting, but their approach differs from Deolalikar and Evenson (1989) in three respects. *First*, Deolalikar and Roller use firm-level -- instead of industry-level -- data from India for the

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period 1975-76 to 1979-80. *Second*, unlike the Deolalikar-Evenson study which estimates the *demand* for patenting, Deolalikar and Roller estimate the *production function* for patenting. In other words, they are interested in understanding the manner in which inventive inputs, such as R&D personnel, R&D expenditures, domestically-purchased technology and foreign-purchased technology, are used by firms to 'produce' an intermediate inventive output, such as patents, conditional on time and on fixed assets.

But perhaps the *third* and most important respect in which the Deolalikar-Roller study differs from all of the other studies reviewed so far is in its explicit control for unobserved, time-persistent firm endowments. These unobserved endowments may include management ability, which would permit well-managed firms to consistently 'produce' more inventions from given levels of inputs than poorly-managed firms, as well as differing propensities across firms to patent their inventions. The endowments may also represent more general industry-specific factors or locational advantages. Failure to control for these effects can result in upwardly-biased estimates of the effect of fixed assets (i.e., firm size) on patenting because of positive correlations between endowments and inventive activity on the one hand and between endowments and size on the other. In other words, firms that innovate more because they are situated in a strategic industry or location, have superior management skills, or are generally well-endowed also happen to be the ones that are large. This gives the incorrect impression that large size is *causing* more innovation. Most previous studies have been unable to control for such unobserved firm effects because of unavailability of panel data.

Deolalikar and Roller find that, after controlling for inventive inputs and for unobserved fixed (firm) effects, firm size, as proxied by fixed assets, does not have any significant impact on the probability of patenting. In other words, inventive output per unit of inventive inputs is unrelated to size.

One shortcoming of most studies on inventive activity in India is that they limit themselves to formal inventive activity, often of the type that takes place in established R&D laboratories

and results in patents. A large majority of innovative activities among Indian firms take place on the shop-floor. Often such activities play a more important role than formal R&D in the technological development of a firm. To understand the determinants of such 'blue-collar' R&D, we conducted a limited survey of 45 manufacturers of tractor-drawn implements in Punjab, Haryana and New Delhi in 1982 in collaboration with The National Council of Applied Economic Research. The objective of the study was to understand whether firms that did not have formal R&D departments engaged in any adaptive inventive activity. The survey covered firms of all sizes. Slightly more than one-half of the firms did not have a formal R&D program. Information was obtained on the number of product and process inventions that were produced in the previous five years, as well as on the number of design changes in products that were introduced during the same period. We attempted to relate the number of such 'inventions' and adaptations to various firm and manager characteristics, including fixed firm assets, age of the firm, age and schooling of the manager, and product mix of the firm.

The results of the analysis indicated a very strong and significant positive, but diminishing, effect of firm size (as proxied by fixed assets) on process and product inventions. The effect of size on design changes was also positive and significant, but the quadratic in size was not significant, indicating no nonlinearities. At the sample means, however, the elasticity of product inventions and design changes with respect to size were less than one, indicating that the *intensity* of product innovations and adaptations decreases with size. However, the intensity of *process* inventions increases with size till a size of Rs. 1.24 million (average firm size in the sample was Rs. 0.56 million) and thereafter decreases.

Thus the bulk of the evidence -- whether at the level of firms or of industries, whether on R&D, patents or informal inventive activities -- indicates at best no significant effect and at worst a negative effect of firm size on the intensity of inventive activity. The only exceptions to this evidence are Lall, Siddharthan, who does find an inverse relationship between R&D intensity and size for most firms but a positive relationship for very large firms (with sales

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turnover in excess of Rs. 600 million), and our study of tractor-drawn agricultural implement manufacturers, for whom we find an *initially* positive relationship between the intensity of process (but not product) inventions and size and an inverse relationship for firms having more than Rs. 1.24 million in fixed assets. The Indian evidence thus largely confirms the evidence from the United States and most developed countries that size is generally not an important determinant of inventive activity.

B. Imports of Foreign Technology

While it would seem *a priori* that R&D and technology imports must be substitutes since firms can make a choice between producing their own technology or licensing it from other suppliers, this need not necessarily be the case in a situation where the bulk of the R&D activity is *adaptive* rather than *basic* or *innovative*. Indeed, it is quite possible that for largely adaptive R&D the relationship between R&D expenditures and technology imports is complementary. This is because invention often takes the form of modification or adaptation of inventions licensed from a foreign supplier to suit, say, local market conditions or local raw materials availability.

For a sample of 370 Japanese manufacturing firms, Odagiri (1983) found that R&D intensity and the intensity of foreign technology use (i.e., royalty payments as a percentage of sales) were positively correlated. However, the positive relationship was statistically significant only for non-innovating firms. These results suggest that the purchase of technology is complementary to *adaptive* R&D but not to *innovative* R&D.

In his analysis of Indian firm-level R&D intensities, Siddharthan included lump-sum payments for foreign technology per sales Rupee as an additional explanatory variable to test the complementarity hypothesis. Lump-sum payments were used in lieu of royalty payments as they constitute 80 per cent of the total payments for import of technology in India. To test

the hypothesis that technology purchase and R&D are complementary for non-innovators and substitutes for innovators, Siddharthan estimated the R&D relationship for the entire sample of firms as well as for private-sector firms only. The assumption here is that public-sector firms in India primarily undertake innovative R&D, as they are mandated to do so by the Government and as they do not have to respond immediately to market pressures (which would presumably make basic or innovative R&D unattractive or nonfeasible). Siddharthan's results are interesting: for the entire sample of firms, he obtains an insignificant effect of technology imports on R&D intensity; however, when public-sector firms are excluded from the analysis, the effect of technology imports on R&D intensity becomes significantly positive. However, this relationship was not as robust when estimated separately for different industry groups.

Lall's results for 100 Indian engineering firms and Katrak's results for a cross-section of Indian industries are broadly similar to Siddharthan's. Using imports of capital and non-capital equipment and expenditures on royalty and technical fees as alternative indicators of technology imports, Katrak too found a weakly positive impact of technology imports on R&D expenditures. He found the positive effect to be weaker for more complex technologies than for simple technologies.

Although all of the above researchers subscribe to the view that a firm's decisions to produce technology (via R&D) and to import technology are determined *jointly*, they still implicitly treat technology import as an exogenous decision to the R&D decision by including the former as an explanatory variable in the R&D equations that are estimated. Given the model of firm decision-making implicit in the authors' analyses, import of technology obviously is an endogenous variable whose inclusion in an OLS-estimated R&D equation will lead to simultaneous-equations bias in the estimates of the latter. If the source of the simultaneity is an unobserved firm-specific effect of the type discussed in the previous section, it is likely that a simple OLS regression of R&D on technology imports will provide an upwardly-biased estimate of the true impact of technology imports on R&D. This would be the case if, say, good managers

used both foreign and own-produced technology more intensively than traditional inputs. Then lack of control for management ability would incorrectly give the impression that larger technology imports were *causing* firms to spend more on R&D.

Deolalikar and Evenson address this problem by considering the demand for purchased and own-produced technology (the latter being proxied by the average number of patents granted to Indian nationals per firm) to be jointly determined by exogenous variables, such as prices, wage rates and fixed factors of production.[5] Thus, the substitution/complementarity relationship between the two types of technologies is indicated by the direction in which the demand for each moves in response to a change in exogenous variables. This empirical treatment of inventive activity and technology purchase is much more in keeping with the idea firms jointly choose the two activities on the basis of economic calculus.

Deolalikar and Evenson find that a large number (although not all) of the coefficients of the domestic patenting and technology import equations have similar signs, which implies that both variables tend to move in the same direction in response to an exogenous change. For instance, in the light industries, the price of fuel has positive and significant effects on the demand for both domestic patenting and purchased technology. Similarly, they find that an increase in *international* inventive activity (proxied by patenting in the United States) stimulates significantly the demands for both activities (see next section). The authors interpret this evidence to imply that imported technology and inventive activity are complements of, rather than substitutes for, each other.

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[5]In contrast to much of the R&D literature in the United States, Deolalikar and Evenson treat technology imports and indigenous inventive activity as variable factors of production. They argue that, in the Indian case, both activities have a real element of variability. Technology purchase is quite variable since many of the contractual arrangement are quite short term in nature. 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.

C. International Supply of Technology and Knowledge

Deolalikar and Evenson argue that, insofar as much of Indian inventive activity involves modification and adaptation of technologies already developed elsewhere, the potential pool or supply of internationally-available technologies may act as a constraint to indigenous inventive activity in India. It may, therefore, be important to include the supply of international inventions as an explanatory variable in the domestic patenting equation. They proxy international inventive activity by the cumulative number of patents granted in the United States in any particular industry during the previous five-year period.

Their results are interesting. Cumulative patenting in the United States in a particular industry strongly stimulates Indian national patenting within the same industry. Deolalikar and Evenson interpret their results to imply that the disclosure effect of U.S. patenting -- whereby Indian firms learn on an invention which they would otherwise not have known about, modify it, and patent an adapted version in India -- dominates the blocking effect -- whereby American and third-country firms patent their inventions in the United States to effectively block Indian and other firms from 'reinventing' the same product or process. The authors obtain an elasticity of Indian national patenting with respect to U.S. patenting of 1.1 for the light industries and of 2.1 for the chemical industries. The corresponding elasticity for the engineering industries is not significantly different from zero. The finding that this elasticity is much larger for the chemical than for other industries probably reflects the lower appropriability of inventions (from the point of view of the inventor firm) in the chemical/pharmaceuticals industries. It is generally well-known that infringement or side-stepping of patents is much easier in these than in other industries.

D. Firm Ownership

Many state-owned firms in India, particularly in industries such as machine tools, heavy electricals and electronics, are mandated by the Government to undertake extensive R&D. Some of these firms were set up in the 1950s as part of India's ambitious import-substituting drive, and were expected not only to reduce India's dependence on imports for its capital goods needs but also for its technology and know-how needs. These firms were, therefore, freed from immediate market pressures and encouraged to have large R&D budgets and staff to assimilate, adapt and eventually import-substitute leading, state-of-the-art technologies.

Table 9 compares the R&D intensities of public vs private firms and of indigenous vs foreign firms. On average state-owned firms have the highest research intensity of any ownership category. But much of the R&D among public sector firms is concentrated in two industries, viz., electrical machinery and pharmaceuticals. In other industries, it is not clear that state-owned enterprises undertake significantly more R&D than privately-owned enterprises.

In their industry-level analysis, Deolalikar and Evenson too found that only in the case of the chemical industries was the presence of state-owned enterprises in an industry associated with greater domestic patenting in that industry. In the engineering industries, there was no significant effect of state ownership on domestic patenting.

Interestingly, Deolalikar and Evenson found that the share of equity held by foreigners in an industry had a significant *negative* effect on domestic patenting in the chemical industries. These results suggest that, holding other variables such as prices, international inventions, and firm size constant, publicly-owned firms engage in more and foreign-owned firms in less inventive activity than other firms. But these results apparently hold only for the chemical industries.

Table 10 shows the functional distribution of R&D expenditures for the different ownership groups. These data bring out the different nature of R&D undertaken in state- vs. privately-owned firms. A significantly larger percentage of R&D expenditures go into basic background research in state-owned than in privately-owned enterprises. The large majority of R&D activity

in the private sector goes into "improving processes and products."

5. Characteristics of Inventors

We had undertaken a survey of inventors in India in collaboration with The National Council of Applied Economic Research. A list of 1,000 inventors was prepared form data on the 1,000 most recent patents granted to Indian nationals in India. A mail survey was initiated in February 1983. By June 1983, 243 inventors had returned usable questionnaires. Roughly 180 survey letters were returned because the inventor was not at the listed address.

Inventions were classified according to whether they were in the light, chemical or engineering industries. The light industries included food products, beverages, tobacco, textiles, wood products, paper, leather products, nonmetallic mineral products, repair services, and miscellaneous industrial products. The chemical industries included rubber and plastics and chemicals. The engineering industries included basic metals, metal products, machinery, electrical machinery, transport equipment, and other manufacturing.

Table 11 provides a summary of inventor characteristics for each industry group. A simple statistical (chi-square) test was applied to determine whether characteristics varied by industry group. Relatively few significant differences (noted by an asterisk) existed.

Perhaps the most noteworthy indicators in the table are the data showing that inventors in India have very high levels of education and training. Almost 90 per cent have finished college, more than half have finished graduate work, and nearly 30 per cent have Ph.D. degrees. Of all college graduates, 88 per cent have science or engineering degrees. In addition, 45 per cent of all inventors have some form of technical training. We also find a significant degree of education and training abroad among Indian inventors.

We find that inventors in the chemical industries are much more likely to have Ph.D. degrees than invetors in the light and engineering industries. However, the proportion of

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Table 11

Characteristics of Indian Inventors by Industrial Class

	Light	Chemical	Engineering	All
Percent Finishing Primary School	93.0	98.6	98.4	97.5
Percent Finishing Secondary School	93.0	97.2	96.9	96.3
Percent Finishing College	81.4	94.6	86.7	88.0
Percent Finishing College Abroad	2.3	5.6	3.1	3.7
Percent Finishing Graduate Work*	46.4	62.2	50.7	56.4
Percent Finishing Graduate Work Abroad	11.6	13.9	7.8	10.3
Percent Finishing Ph.D. Degrees*	11.6	62.5	15.6	28.8
Percent Finishing Ph.D. Degrees Abroad*	7.6	18.1	4.7	9.1
Percent Finishing Technical Training	46.5	40.2	47.6	45.3
Percent Finishing Technical Training Abroad	14.0	19.4	10.9	14.0
Percent Working in Public Firms	18.6	25.0	30.5	26.8
Percent With Prior Patents	46.5	56.9	45.3	49.0
Percent With Patent Pending	46.5	54.1	38.1	44.4
Percent With Licenses	9.3	13.9	13.3	12.8

Significant differences at 5% level.

inventors with Ph.D.'s in the light and engineering industries is not negligible. Clearly, Indian invention is a field of activity in which the highly-educated compete.

6. Conclusions and Policy Implications

Much of Indian technology policy has been based on the premise that imported technology and indigenously-generated technology are substitutes. In the 1950s and 1960s, Indian technology policy was relatively liberal and its scope, limited. However, from the mid-1960s, the policy became much more selective and discriminatory against technology imports. While conservation of scarce foreign exchange was certainly an element in the policy change, there was a real perception that indigenous technological activities could only be stimulated via restrictive and selective imports of technology. The large apparatus of the Government was organized to monitor foreign technical collaborations and prevent 'over-imports' of imported technology.

Unfortunately, this technology policy had little success in promoting technological development in Indian industry. In fact, several researchers have argued that the very restrictive nature of the technology policy has been largely responsible for the technological obsolescence of Indian industry. As we have noted in this paper, most of the empirical literature directly contradicts the presumption that technology imports and indigenously-generated technology are substitutes. If anything, the relationship that is often observed is one of complementarity. As Desai (1985: 2094) puts it, "... Import restrictions on technology do not produce import-replacing technology.... Freer import of technology would channel local research and development in directions where technology from abroad is not available or accessible and where returns are high."

Another important policy implication arises from the empirical results obtained by Deolalikar and Evenson on the strong diffusion of inventions from the United States to India. The

finding that international inventions stimulate Indian invention should lead to a possible re-evaluation 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. The Deolalikar-Evenson analysis, which is based on data from the period before the new patent policy, suggests that the legal and institutional setting in India during the 1960s was quite conducive to enabling both indigenous inventive activity and technology imports to benefit from international inventions. 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 indigenous adaptive R&D. Further study, using post-1970 data, is required to determine whether this indeed happened.

The finding that firm size is at best not related to research intensity or the intensity of inventive activity and at worst inversely related has important policy implications. Much of Indian technology policy has indirectly favored large firms, particularly in the public sector. For instance, the industries in which technology imports are banned are typically those with large numbers of small firms. The empirical results on the effects of size suggest that greater neutrality of the government between small and large firms may be needed for indigenous technological development.

It is important to note that government R&D policy is oriented largely, if not entirely, toward formal R&D activities of firms undertaken in government-registered R&D departments. To the extent that a large portion, indeed bulk, of indigenous inventive activity in a country, such as India, is informal in nature and carried out on the shop-floor, it is important for government R&D incentives to cover both formal and informal technological activities of firms. Often, 'blue-collar' R&D of the informal kind has as large, if not larger, returns as formal R&D.

Finally, more empirical work, using firm- and industry-level data, needs to be done on the impact of non-technology policies of the government, such as trade, anti-trust and general development policies, on indigenous inventive activity at the firm level. Little, if anything, is

known about how inventive activity differs across industries that receive heavy tariff protection and those that do not, what the impact of capacity licensing policies has been on inventive activity, and how market structure influences innovation in Indian industry.

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Table 9
R&D Expenditures on Current Account as % of Sales, By Ownership Group, 1977-78 to 1980-81

Industry	MNC Subsidiaries	Minority Foreign Capital Firms	Indian Firms with foreign collaboration	State-Owned Firms
Foods, Beverages & Tobacco	-	35	.01	-
Textile Products	-	.05	.53	-
Transport Equipment	.59	.78	.33	.59
Machinery & Machine Tools	.46	.37	.81	.44
Metals & Metal Products	.48	.21	.07	.12
Electrical Macinery & Apparatus	.37	.93	.62	3.70
Chemicals & Chemical Products	.84	.56	.33	.24
- Basic Industrial	.92	.43	.28	.12
- Drugs and Pharmaceuticals	1.24	.88	.34	2.91
- Others	.53	.58	.78	.05
Rubber Goods	-	.22	-	-
Miscellaneous	-	.27	.54	.48
Entire Manufacturing Sector	.62	.31	.51	.75

Source: Reserve Bank of India (1985).

Table 10
Functional Distribution of R&D Expenditures on Current Account, 1977-78 to 1980-81

Industry	MNC Subsidiaries	Minority Foreign Capital Firms	Indian Firms with foreign collaboration	State-Owned Firms
Basic background research	28.2	12.4	4.3	44.5
Improving processes and products	53.8	52.6	67.8	36.3
Developing new products and processes	11.3	31.7	25.5	18.6
Contribution to outside agencies	6.6	3.3	2.4	.6
All functions	100.0	100.0	100.0	100.0

Source: Reserve Bank of India (1985).