

DEPARTMENT OF ECONOMICS

ISSN 1441-5429

DISCUSSION PAPER 27/07

**TECHNOLOGY AND SPILLOVERS: EVIDENCE FROM INDIAN MANUFACTURING  
MICRO-DATA**

**Shishir Saxena<sup>1</sup>**

**Abstract:**

This paper finds that technology stocks and spillovers, have significantly affected the output of Indian manufacturing firms, over the period 1994 to 2006. The technology of a firm is measured, as embodied in its recent stock of plant & machinery, as well as generated through its own R&D. Moreover, investments in both these types of capital by a firm, also generate learning and level of development effects, for all other firms in that industry.

JEL classification: L6, E22, D24, D62, O30

Key words: Indian manufacturing, equipment, R&D, spillovers

---

<sup>1</sup> Department of Economics, Monash University, Caulfield East, Victoria 3145.  
Tel: +61 (3) 990 34513; Fax: +61 (3) 990 31128;  
E-mail: [shishir.saxena@buseco.monash.edu.au](mailto:shishir.saxena@buseco.monash.edu.au).

## 1. Introduction

Discussion of the positive effects of investment in plant & machinery and R&D is reasonably extensive in economic theory. Nelson (1964) and Greenwood *et al.* (1997) among others, argue that machinery of a relatively new vintage embodies the latest technology, and therefore, fosters higher labour productivity growth. Meanwhile, DeLong and Summers (1991) argue that investment in machinery generates significant learning effects, which spill over to other firms (Shaw 1992). Furthermore, Romer (1986) stresses investment in research and development as an engine of long-run growth, while Griliches (1979) highlights the favourable impact of spillovers from such investments. The empirical literature using firm-level data from developed countries has established, that a firm's equipment embodies the latest technology (Sakellaris and Wilson 2004), and that R&D and its spillovers, promote growth (Wieser 2005). However, evidence on these claims from the developing world, is either lacking or contentious. Moreover, no studies, either from developed or developing countries, have considered the effect of spillovers from investment in machinery on output.

Indian manufacturing is an appropriate case to examine in this context. Several authors, including, Balakrishnan and Babu (2003) and Kalirajan and Bhide (2005), raise growing concerns, about the slower than expected growth in manufacturing output, over the second half of the 1990s, following an initial spike in the first half of that decade. Uchikawa (2001) and Kumar and Aggarwal (2005) highlight the concomitantly declining rates of investments in physical capital and R&D, in the sector. This is disconcerting, given that Panagariya (2007) attributes the difference in growth rates of India and China, solely to the lackluster industrial performance in India. Although investments are indispensable for the growth of manufacturing output, especially of a fast progressing economy, there is hardly any evidence using recent data, on the impact of such investments, and their associated externalities on manufacturing output in India. Existing firm-level studies analyze data from the period between 1975 and 1990, and use a small sample of firms. Nonetheless, they confirm the favourable impact of some types of investment and their spillovers on output. For instance, Hasan (2002) finds that recently purchased machinery incorporates superior technology, which significantly affects output. Raut (1995), Basant and Fikkert (1996) and Hasan (2002) conclude, that although R&D proves to be insignificant for a firm, its technology purchases and the spillover from such R&D tend to exert a significant positive impact.

This paper provides recent evidence on the impact of investment in plant & machinery and R&D, and their associated spillovers, on growth of output of Indian manufacturing. More importantly, it is the first piece of research, to simultaneously consider two different sources of spillovers for a firm; one each, from the industry-wide stock of equipment and R&D.<sup>2</sup> The industry-wide stock of R&D measures the available industry-wide knowledge generated from advances in technology, which increases the productivity of human capital associated with the research sector of a firm (Romer 1990). On the other hand, the industry-wide stock of equipment is meant to capture either or both, of the following effects. The first is based on an extension of the “learning by watching” hypothesis, which argues that investment in machinery by one firm has a “demonstration effect” onto production workers of other firms (King and Robson 1993), as it creates an intangible capital stock (Hammond and Rodriguez-Clare 1993; Greiner and Semmler 2002). The second, and the less known, is the level of development effects, dating back at least to Frankel (1962). According to this argument, each firm’s output is an increasing function of the level of development achieved by that industry, an idea, similar in essence to that of “balanced growth” advanced in Rosenstein-Rodan (1943). Whereas Frankel (1962) chooses capital intensity to represent the level of development, this research uses the industry-wide stock of equipment as its measure. These two spillovers for a firm are independent of each other. Learning from investments/ level of development effects, impact(s) output of all firms, regardless of advances in knowledge, and vice versa. Furthermore, the industry-wide equipment stock appropriately measures the level of development of an industry, which, the industry-wide R&D stock may not, as not all firms invest in R&D.

The rest of the paper is organised as follows. Section 2 outlines the augmented production function framework used in this study. Section 3 provides details on the data used and the method of construction of production variables. It also reflects on several econometric issues. Section 4 presents empirical results. The final section outlines implications of the results and adds a number of concluding remarks.

---

<sup>2</sup> The stock of equipment comprises the stocks of plant & machinery and transportation & communication equipment. It is larger in magnitude compared to the stock of plant & machinery alone.

## 2. Conceptual framework

The econometric model is based on an extended Cobb-Douglas production function framework. It is postulated that output ( $Y$ ) of the  $i^{\text{th}}$  firm of industry  $j$  at time period  $t$ , is a function of its private inputs, including the stock of capital ( $K$ ), labour ( $L$ ), materials ( $M$ ), and R&D ( $R$ ). The share of recently purchased machinery in the total capital stock approximates the effect of technology embodied in a firm's machinery ( $RPM/K$ ). The spillover effects are captured by the industry-wide stocks of equipment ( $EQI$ ) and R&D ( $RDI$ ), net of a firm's own stocks of these variables. It is assumed, as in Los and Verspagen (2000), that technical progress is endogenised in a firm's own R&D and equipment, and therefore, a time trend treating such progress as exogenous is not included in the production equation.<sup>3</sup>

$$Y_{ijt} = A K_{ijt}^{\alpha} L_{ijt}^{\beta} M_{ijt}^{\gamma} R_{ijt}^{\delta} (RPM/K)_{ijt}^{\rho} EQI_{ijt}^{\epsilon} RDI_{ijt}^{\omega} \quad (1)$$

The superscripts in Equation (1), measure the elasticity of the concerned inputs. A logarithmic transformation of this equation is used to measure the elasticities of the concerned inputs,

$$y_{ijt} = a + \alpha k_{ijt} + \beta l_{ijt} + \gamma m_{ijt} + \delta r_{ijt} + \rho (rpm/k)_{ijt} + \theta eql_{ijt} + \omega rdl_{ijt} + \epsilon_{ijt} \quad (2)$$

where lower-case letters denote natural logarithm of the corresponding variable. In this analysis, R&D is treated as a stock variable, and not as a flow. While Terleckyj (1974) advocates using the latter, Griliches (1979) argues in favour of conversion of R&D expenditures into a stock variable. This is because the contribution of R&D extends beyond the time period in which it is conducted.

## 3. Data and variable construction

This study uses data from 4,971 manufacturing firms, over the period 1994 to 2006. This data is taken from Prowess, an electronic database, maintained by the Centre for Monitoring Indian Economy (CMIE), Mumbai, which has built the largest database on Indian firms.

---

<sup>3</sup> Regressions inclusive of a time trend were also tried. Results were found to be of the same sign and significance for all inputs. However, the coefficient on R&D and its spillover were found to be relatively lower when such a trend is included. This gives credence to the assumption, that technology embodied in R&D captures technological progress.

Prowess compiles information from the annual reports of large- and medium-sized Indian firms including government undertakings, whose shares are regularly traded on major Indian stock exchanges. It covers nearly 5,000 manufacturing firms encompassing all manufacturing industries, which collectively account for 70 per cent of total value-added by Indian manufacturing. However, this dataset has a limitation in that, it does not account for very small firms from the unorganised sector. Therefore, any industry dominated by small-scale firms is under-represented in this database. Nevertheless, there's considerable variation in the size of firms for all industries included in the dataset.

To estimate the parameters in Equation (2), it is essential to have deflated measures of output and inputs. Nominal values of these variables drawn from Prowess have been deflated using industry-wide deflators (up to 5-digits when available) accessed electronically, from the Annual Survey of Industries (ASI), which is the principal source of industrial statistics in India; and various publications of the Central Statistical Organization (CSO), Government of India. The methods used, are outlined below.

**Output (Y):** The current value of output is deflated using the 5-digit commodity-wise Wholesale Price Index of India (WPI), with 1993-94 as the base year, available electronically from the Office of the Economic Adviser (2000).<sup>4</sup>

**Physical capital (K):** The aggregate of the net fixed capital stock ("NFCS" hereafter) of equipment (plant & machinery, transport and communication equipment) and structures (land & buildings), at constant 1994 prices, is chosen as the measure. The perpetual inventory method ("PIM" hereafter) is used to convert expenditure flow on capital of both types into a stock variable. The depreciation rate chosen is 10 per cent for equipment and 3 per cent for structures. To apply the PIM, a base year capital stock of each type of capital needs to be determined. This is determined using the methodology adopted by Basant and Fikkert (1996).

The gross value of each type of asset is reported at historical cost. To derive NFCS in 1994, the average age ("AA" hereafter) of each type of capital needs to be determined. This is done by deducting the reported net value of the total capital stock from its gross value, and assuming that equipment and structures at that time, took 20 and 50 years respectively to

---

<sup>4</sup> The financial year in India runs from 1<sup>st</sup> April to 31<sup>st</sup> March. For expositional convenience, 1993-94 is written as 1994 hereafter, and the practice is followed throughout this paper

depreciate fully, as given in CSO (1989). One drawback of this assumption is that both equipment and structures are assumed to be of the same vintage, however, no other feasible alternative is available. Using AA, the reported value of the asset in “1994-AA” prices is deflated to 1994 prices using a price index constructed for each type of asset with the help of the constant and current price series of gross fixed capital formation on “construction” and “machinery & equipment”, available electronically from CSO (2006).<sup>5</sup> NFCS of equipment ( $K^{Equip}$ ) and structures ( $K^{Str}$ ) in 1994 prices, are then constructed as follows:

$$K_{i,1994}^{Equip} = \frac{Equip_{i,1994}}{CD_{1994-AA_i}^{Equip}} * (1 - 0.10)^{AA_i} \quad (3)$$

$$K_{i,1994}^{Str} = \frac{Str_{i,1994}}{CD_{1994-AA_i}^{Str}} * (1 - 0.03)^{AA_i} \quad (4)$$

where  $Equip$  and  $Str$  are the book values of equipment and structures respectively, reported in 1994;  $CD_{1994-AA_i}^{Equip}$  and  $CD_{1994-AA_i}^{Str}$  are the deflators for equipment and structures respectively for “1994-AA<sub>i</sub>”. After having determined the initial values of NFCS for each type of asset, the PIM is used to convert subsequent investments into a stock variable.

**Labour (L):** The total number of employees is used as the measure of labour. It is not reported in Prowess and has been calculated by dividing each firm’s consolidated wage bill (wages and salaries paid to all types of workers including managers and owners and contract workers), by the 4-digit industry average for compensation per employee per year. The latter is calculated by dividing “total emoluments to employees” with “total persons engaged”, both of which are available from the ASI, and have been accessed electronically from [www.indiastat.com](http://www.indiastat.com) (2006).<sup>6</sup>

**Raw materials (M):** The real value of all intermediate inputs (raw materials, power and fuel, stores and services) at 1994 prices is chosen as the measure. The Input-Output Transactions Table of India 1998-99, which has information on raw material use segregated by 4-digit

---

<sup>5</sup> Data on capital deflators with base 1994 is available only up to 2004. Thereafter, the new series with base 2000 has been introduced. For 2005 and 2006 therefore, this study has generated deflators using the growth rates of deflators provided by the new series.

<sup>6</sup> ASI data for 2005 and 2006 is still not available electronically. For these two years, data has been extrapolated based on the mean growth of wages over the period 1994 to 2004.

industry code, available electronically from CSO (2006), is used to deflate nominal values. The price of each raw material is deflated using the 5-digit commodity-wise WPI series. The industry-specific materials deflator is calculated as the weighted average of the deflated values of all raw-materials, with composition of raw material used, acting as weights.

**R&D capital stock ( $R$ ):** Net real R&D stock at constant 1994 prices is the measure used. PIM is used to convert a firm's expenditure on R&D into a stock variable. The chosen rate of depreciation is 15 per cent, and it is assumed that R&D affects output with a one-year lag (Coe and Helpman 1995), and that R&D ceases to have an impact on output after five years (Griliches 1979). The initial stock in 1994 is determined as the cumulative past real R&D expenditures, including technical fees and royalty paid, as follows:

$$r_{i,1994} = \sum_{\tau=0}^5 rdex_{i,1993-\tau} (1-\delta)^{\tau} \quad (5)$$

where  $r_{1994}$  is the R&D stock in 1994, and  $rdex_{1993}$  is the R&D expenditure inclusive of technical fees paid by the firm in 1993. Raut (1995) argues, that in a developing country like India, disembodied technology purchases by a firm (technical fees and royalty), also form a source of its private knowledge. Hence, these are also included in R&D expenditures. Analysis was also carried out by excluding expenditures on imports of such disembodied technology and results were found to be robust to this change. The series used to deflate R&D expenditure is the average of the deflator series for equipment capital and wages for industrial workers. The latter is obtained from the Ministry of Labour (2006). The R&D stock for subsequent years is generated using the PIM as follows

$$r_{i,t+1} = r_{i,t} (1-\delta) + rdex_{i,t} \quad (6)$$

Since the final sample contains many firms which do not expend on R&D (65% of total observations), following Hasan (2002), 1 has been added to all observations on the final R&D stock variable for these firms, to avoid taking logarithms over a zero R&D value.

**Recent stock of plant & machinery ( $RPM$ ):** As adopted in Hasan (2002), the stock of RPM is constructed as the cumulative past real expenditures on plant & machinery, as follows:

$$RPM_{it} = \sum_{s=0}^4 Inv_{t,t-s} (1 - \delta)^s \quad (7)$$

In this equation, *Inv* is the real expenditure on plant & machinery, calculated as the difference between their book values of two consecutive years. It is deflated using the equipment capital deflator.<sup>7</sup> To avoid collinearity, the stock of recent investments is considered as a ratio of total physical capital (*RPM/K*)

**Equipment spillover (*EQI*):** This is calculated as the aggregate of the equipment capital stock of all firms in the industry, net of the capital stock of the firm under consideration:

$$EQI_{it} = \sum_t K_{it}^{equip} - K_{it}^{equip} = \sum_{q \neq i}^N K_{qt}^{equip} \quad (8)$$

where *N* is the number of firms in the same industry as the *i*<sup>th</sup> firm.

**R&D spillover (*RDI*):** This is measured as the aggregate R&D capital stock of all firms in the same industry as the *i*<sup>th</sup> firm, net of its own R&D stock.

$$RDI_{it} = \sum_t R_{it} - R_{it} = \sum_{q \neq i}^N R_{qt} \quad (9)$$

reports descriptive statistics of the variables. It also provides information on the export earnings of industries, which is utilized in the following empirical analysis. The final unbalanced panel dataset comprises 42,794 observations.

---

<sup>7</sup> The recent stock of plant & machinery is chosen to comprise of investments in the past four years. Different values of two and three years were also tried, but results remained robust to these changes.

Table 1: Summary statistics of production variables from Indian manufacturing firms 1994-2006

Industry	No of firms	No of Obs.	Output	Physical capital	Labour	Materials	R&D	Recent equipment	Equipment spillover	R&D spillover	Export
<b>Chemicals</b>	863	7,635	921	467.63	1,231	550	26	182.61	302,355	22,258	18
<b>Textiles</b>	748	6,542	609	315.44	1,324	370	4	124.79	172,791	3,358	17
<b>Base Metals</b>	598	4,986	1,478	1,010.63	2,037	944	19	410.86	469,630	11,318	29
<b>Electronics</b>	603	4,628	1,770	184.71	1,807	273	18	79.57	79,427	11,202	5
<b>Rubber &amp; Plastic</b>	364	3,404	767	434.40	796	492	12	193.63	121,977	4,513	13
<b>Food, Beverages &amp; Tobacco</b>	355	2,962	763	276.11	2,189	404	5	107.84	65,387	1,792	10
<b>Transport</b>	285	2,609	1,904	671.81	2,447	1,213	57	273.34	138,995	15,858	20
<b>Non-Electrical Machinery</b>	283	2,569	1,132	406.35	2,730	690	34	94.35	70,465	9,528	12
<b>Non-Metallic Minerals</b>	274	2,450	981	600.73	1,733	494	8	247.39	121,107	2,357	32
<b>Electrical machinery</b>	235	2,172	1,019	285.68	1,264	502	15	91.84	37,024	2,991	7
<b>Pulp &amp; Paper</b>	197	1,679	489	381.48	1,175	320	1	136.96	49,879	270	3
<b>Misc. Manufacturing</b>	95	550	313	61.12	524	144	1	26.05	4,264	149	4
<b>Leather</b>	51	416	386	107.70	1,941	191	2	30.54	2,870	121	20
<b>Wood</b>	20	192	259	248.05	1,435	187	1	71.46	2,330	16	3
<b>Aggregate Manufacturing</b>	4,971	42,794	1,055	451.54	1,627	547	17	177.38	182,588	9,383	16

Notes: All values are firm means from 1994 to 2006.

All values are in constant million Indian Rupees, except for labour, which is in actual numbers.

For estimation of Equation (2), firm-level data is grouped by 2-digit industry code, as also at the level of Aggregate Manufacturing. Furthermore, the fourteen 2-digit industries are classified as either capital- and labour-intensive, or technological- and non-technological intensive, based on mean capital and technological intensity of all firms in the industry. The former is measured as the total physical capital stock divided by the number of workers employed, whereas the latter is measured as the R&D expenditure of a firm divided by its net sales value. This procedure aggregates all fourteen 2-digit industries into four larger sub-samples comprising seven 2-digit industries each. Details are provided in **Error! Reference source not found.** Note that, there may be firms in the labour-intensive industries, which have a higher capital intensity compared to firms in the capital-intensive industries, and vice-versa, and similarly for technological- and non-technological-intensive industries. This is because the aggregation is based on mean levels.

**Table 2:** Details of capital and technological intensity by industry

<b>Industry</b>	<b>Capital intensity</b>	<b>Industry</b>	<b>Technological intensity</b>
<b><u>Capital-intensive</u></b>	<b>1.43</b>	<b><u>Technological-intensive</u></b>	<b>0.0061</b>
Base Metals	2.52	Electronics	0.014
Rubber & Plastic	1.49	Chemicals	0.0071
Chemicals	1.30	Transport	0.0035
Electronics	1.24	Non-Electrical Machinery	0.0029
Textiles	1.15	Misc. Manufacturing	0.0026
Pulp & Paper	1.07	Electrical Machinery	0.0021
Non-Metallic Minerals	0.81	Rubber & Plastic	0.0016
<b><u>Labour-intensive</u></b>	<b>0.63</b>	<b><u>Non-technological-intensive</u></b>	<b>0.00083</b>
Electrical Machinery	0.81	Non-Metallic Minerals	0.0011
Food, Beverages & Tobacco	0.67	Base Metals	0.001
Transport	0.66	Textiles	0.00083
Misc. Manufacturing	0.57	Food, Beverages & Tobacco	0.00054
Non-Electrical Machinery	0.52	Pulp & Paper	0.00044
Leather	0.42	Wood	0.00041
Wood	0.31	Leather	0.00033
<b>Aggregate Manufacturing</b>	<b>1.22</b>	<b>Aggregate Manufacturing</b>	<b>0.0037</b>

To examine stationarity of production variables, this study conducts panel unit root tests based on the Im, Pesaran and Shin (IPS), and Maddala and Wu (MW) tests. Results reported in **Error! Reference source not found.** for data from aggregate manufacturing convincingly reject the presence of a unit root for every variable. Both these tests find all variables stationary. Results from disaggregated samples are not reported here due to space limitations; however, the results from these disaggregated samples also reject the presence of a unit root.

**Table 3:** Results of panel unit root tests for aggregate manufacturing

Variables (in logs)	IPS	MW
Output	(-)216.626***	11351***
Physical capital	(-)7.6E+11***	13512.4***
Labour	(-)22.3692***	11180.7***
Materials	(-)24.2702***	11193.3***
Recent plant & machinery	(-)1.4E+12***	7440.19***
Equipment spillover	(-)7.40474***	17132.5***
R&D	-	6303.62***
R&D spillover	(-)42.3863***	20322.9***

Notes: The null hypothesis for each of these tests is presence of a panel unit root.

\*\*\* displays significance at 1 per cent level.

All tests include individual effects and a deterministic time trend.

Lag selection is based on the Schwartz Information Criterion

The analysis is based on the fixed effects panel data technique. Note however, that the modified Wald-test and the test based on Wooldridge (2002), suggest that residuals are both heteroskedastic and serially correlated of the first order. In order to correct the standard errors, the fixed effects estimator proposed by Baltagi and Wu (1999) is used. This estimator corrects for AR(1) and ensures homoskedasticity, and is the only suitable estimator to handle unbalanced panel data when the residuals do not follow the standard normal assumptions.<sup>8</sup>

<sup>8</sup> Regressions based on the normal fixed effects estimator using robust standard errors, as well as the Prais-Winsten Panel Corrected Standard Error estimator, were also tried. However, best results were found with use of the Baltagi and Wu (1999) estimator, as it is the only suitable estimator for an unbalanced panel in the presence of AR(1) correlation. Regressions using this estimator were also tried, and results were generally found to be in conformity with those reported here.

## 4. Empirical findings

This section presents production function estimates of Equation (2). The discussion begins with results from aggregate samples and sub-samples based on capital and technological intensity, and then considers results from 2-digit disaggregated industries.

### 4.1. Results from aggregate samples

**Error! Reference source not found.** displays results for aggregate manufacturing and samples based on capital and technological intensity.

**Table 4:** Results for aggregate manufacturing using Cobb-Douglas technology with correction for AR(1)

Variable (in logs)	Aggregate Manufacturing	Capital-intensive	Labour-intensive	Technological-intensive	Non-technological-intensive
Physical capital	.059***	.068***	0.006	.092***	.006
Labour	.247***	.253***	.207***	.28***	.207***
Materials	.595***	.569***	.711***	.531***	.677***
Recent equipment	.016***	.016***	.021***	.015***	.019***
Equipment spillover	.172***	.216***	.112***	.186***	.205***
R&D	.0031***	.0032***	0.002	.0033***	.0028*
R&D spillover	.056***	0.018	.081***	.062***	-0.002
<i>No of obs.</i>	29,459	21,501	7,952	16,028	13,434

Notes: \*\*\* significant at 1 per cent level; \*\* significant at 5 per cent level; \* significant at 10 per cent level.

Time dummies included in all regressions.

These results are highly convincing. Most coefficients are significant at the 1 per cent level. The estimates of all conventional inputs (physical capital, labour and materials) are of an acceptable magnitude. It can be observed that both capital-and technological-intensive industries have a higher coefficient on physical capital compared to other industries, as would be expected. For labour- and non-technological-intensive industries however, this coefficient is insignificant.

Furthermore, the stock of recent equipment is found to be highly significant for all industries, including aggregate manufacturing. (Note that this stock could comprise of either

domestically purchased and/or imported machinery). The results suggest, that a 1 per cent increase in the recent stock of machinery, leads to between a 1.6 per cent and 2.1 per cent increase in output, for different types of industries. Its contribution is between one-fourth and one-fifth, relative to that of total physical capital, for all industries.

The evidence is also strongly conclusive in favour of a positive spillover from the industry-wide equipment stock. Its coefficient is positive and statistically significant for aggregate manufacturing and all smaller sub-samples. This ratifies Frankel's claim, that output of a firm is positively affected by the level of development of that industry, as captured by the industry's equipment stock. The elasticity of the spillover, is found to be higher relative to that of physical capital and labour, and ranges from 11.2 per cent for labour-intensive industries to 21.6 per cent for capital-intensive industries, and is measured at 17.2 per cent for aggregate manufacturing. This suggests that a firm benefits considerably, from the learning effects from investments in equipment, of all other firms in that industry.

It is also unambiguous from these results that R&D contributes significantly towards growth of output, of all industries, except the labour-intensive industries. This is interesting to note, as previous studies, had not found a firm's own R&D's contribution to be significant in India. Even the non-technological-intensive industries gain from it. The elasticity of R&D is measured at between 0.28 per cent and 0.33 per cent for each sample. For total manufacturing, it is measured at 0.3 per cent. As would be expected, technological-intensive industries gain the most from R&D, although the coefficient does not vary by a huge margin among all samples.

The effect of the R&D spillover is also positive and statistically significant for all types of industries, except the capital- and non-technological-intensive industries. It is within the range of 5 per cent and 8 per cent for all samples. As would be expected, technological-intensive industries gain more from this spillover relative to aggregate manufacturing, although labour-intensive industries gain the most from this spillover. This is a significant finding, as it highlights, that India's predominant labour-intensive industry, which does not seem to gain from own R&D, does have a beneficial impact from the available industry-wide knowledge. It is also striking to note that the effect of the R&D spillover is much larger compared to own R&D. Other studies, on both developed and developing countries, including India, reach a similar conclusion (Wieser 2005). Therefore, it can be inferred that a firm learns much more

from knowledge available industry-wide, as compared to knowledge either generated or purchased on its own.

The reader is reminded though, that the proportion of firms investing in R&D is relatively low across industries, including for aggregate manufacturing. Since the effect of R&D and its spillover may differ between R&D firms and the rest, regressions were also run for all industries, considering the smaller sample of only those firms, which invest in R&D (R&D sample). However, these results did not yield any interesting light on the analysis, and hence, are not reported here. The coefficient on R&D and its spillover were found to be of a similar magnitude, as those reported above in **Error! Reference source not found.** Although, when using the R&D sample of firms, it was observed for aggregate manufacturing, and the labour- and less-technological-intensive industries, that the R&D coefficient is relatively higher, and significant, even for labour-intensive industries, compared to that reported above. Further, the coefficient on the R&D spillover was found to be significant for even capital- and technological-intensive industries.

Comparing the estimated elasticities of the two spillover effects across industries, it can be observed, that the equipment spillover has a higher impact on output, compared to the R&D spillover. This could be because of one or both of the following arguments. Either the development effects of an industry are much more important to a firm of that industry, compared to the learning effects from available industry-wide R&D. Or else, the effects of trial and error and experience of all other firms, is a more valuable source of information for a firm relative to the industry-wide R&D. This could be because R&D intensity in India is very low.

#### 4.2. Results from disaggregate samples

When considering data for disaggregated 2-digit industries, it was found, that the two spillover variables were highly correlated. The degree of collinearity in some cases, was observed to be as high as 0.95. Including both these variables in a single regression consistently yielded insignificant and negative estimates of these variables, across industries. Therefore, several proxies were considered for these variables. For instance, the industry-wide investments in equipment and industry-wide stock of total physical capital were tried instead of industry-wide stock of equipment; and industry-wide R&D expenditures were chosen

instead of industry-wide stock of R&D. However, this did not mitigate the problem. There was no single proxy, which could be used across industries, without leading to collinearity. It was considered appropriate therefore, to use two separate regressions, for analysing the impact of each of these spillover variables, without making use of any proxies. Two different specifications of Equation (2) were used. Specification 1 estimates the impact of conventional inputs, the recent machinery stock, and industry-wide equipment, whereas, Specification 2 assesses the impact of conventional inputs, the recent machinery stock, R&D and industry-wide R&D. Results are reported in **Error! Reference source not found.** Since two different regressions are estimated for each industry, it should be noted that the estimates of conventional inputs and the recent machinery stock in these two regressions differ in magnitude, although are same in sign and significance.<sup>9</sup>

The coefficients on conventional inputs, across industries, are found to be of an acceptable magnitude. If we focus on Specification 1, it can be observed that a few capital-intensive industries have a higher coefficient on physical capital, relative to others. For instance, the elasticity of capital is 9.1 per cent for Chemicals and 14.3 per cent for both Non-Metallic Minerals and Electronics. For other capital-intensive industries such as Rubber & Plastic and Paper, it is insignificant. On the other hand, for Base Metals and Food, a labour-intensive industry, it is negative and significant. That this coefficient is negative and significant (insignificant), for a few industries, could be because of gestation lags. Balakrishnan and Babu (2003) have reported a significant increase in the incremental capital output ratio over the 1990s, especially in these industries. To substantiate the claim of gestation lags, regressions were re-run for both Base Metals and Food (which have a negative and significant coefficient on capital), by introducing one-period gestation lags. Results were found to support the claim. For Base Metals, the coefficient on physical capital turns positive and significant, with the introduction of gestation lags, whereas for Food, the coefficient remains negative, although loses significance.

---

<sup>9</sup> However, there are a few exceptions when using specification 2. For Paper, the coefficient on physical capital is negative (same as Specification 1), though, significant. On the other hand, for Leather, this coefficient is positive (same as Specification 1), though, significant. For electronics, the coefficient on recent equipment remains positive, but loses significance.

**Table 5: Results for disaggregate manufacturing using Cobb-Douglas technology with correction for AR(1)**

Variable (in logs)	Chemicals	Textiles	Metals	Electronics	Rubber	Food	Transport	Non-Electrical	Minerals	Electrical	Paper	Misc. Mfg	Leather	Wood
<b>Specification 1: <math>Y_{it} = A K_{it}^{\alpha} L_{it}^{\beta} M_{it}^{\gamma} RPM_{it}^{\delta} EQ_{it}^{\epsilon}</math></b>														
Physical capital	.091***	.036**	-0.54***	.143***	-0.016	-.114***	.059***	.061***	.143***	0.025	-0.033	.168**	0.081	-0.076
Labour	.18***	.185***	.217***	.462***	.123***	.329***	.142***	.185***	.126***	.099***	.254***	.286***	.365***	.156***
Materials	.669***	.674***	.691***	.276***	.873***	.69***	.724***	.683***	.581***	.934***	.84***	.287***	.566***	.92***
Recent equipment	0.005	.023***	.037***	.036***	.017**	.021*	0.001	0.006	0.009	0.011	.031***	.092***	-0.008	0.03
Equipment spillover	.157***	.198***	.227***	.38***	.094***	.253***	.154***	.178***	.173***	0.03	.116***	.373***	.16*	.1**
No of obs.	5,860	5,000	3,768	2,983	2,648	2,297	2,157	1,909	1,803	1,480	1,283	329	316	150
<b>Specification 2: <math>Y_{it} = A K_{it}^{\alpha} L_{it}^{\beta} M_{it}^{\gamma} RPM_{it}^{\delta} R_{it}^{\epsilon} RD_{it}^{\zeta}</math></b>														
R&D –Total	0.000	-0.002	.006**	0.005	.005**	.006*	0.000	0.000	0.001	0.001	0.006	0.002	0.006	0.006
R&D – Current	0.000	-0.001	0.005	-0.006	0.000	.010**	0.000	0.001	-0.015	0.006	0.012	.165*	.792**	0.016
R&D – Capital	-0.006*	0.004	0.001	-0.004	-0.001	0.007	0.000	0.001	0.007	0.008**	.016***	0.029	-1.220	0.000
R&D spillover	.172***	.215***	.288***	.394***	.131***	.346***	.156***	.187***	.223***	0.04	.155***	.456***	-0.014	.123**
No of obs.	5,363	4,594	3,476	2,768	2,459	2,096	1,978	1,775	1,657	1,371	1,184	305	287	140

Notes: \*\*\* significant at 1 per cent level; \*\* significant at 5 per cent level; \* significant at 10 per cent level.

Time dummies included in all regressions.

In Specification 2, coefficients on physical capital, labour, materials, and recent stock of plant & machinery, were observed to be of the same sign and significance as in Specification 1. Exceptions are pointed out in footnote 9.

In Specification 2, the stocks of R&D-total, R&D-current and R&D-capital are constructed using the total, current and capital expenditures on R&D respectively. Three different regressions are used to measure the coefficients on each. The R&D spillover is constructed from R&D stocks from total R&D expenditures.

Furthermore, the recent stock of machinery has a considerable positive impact for several industries, especially capital-intensive industries. Such industries, for instance, Textiles, Base Metals, Electronics and Rubber & Plastic, gain the most from the technology embodied in such machinery. On the other hand, only two of the seven labour-intensive industries gain significantly from this stock, those being, Food and Miscellaneous Manufacturing. For others, the coefficient is insignificant, although positive. The findings suggest that a 1 per cent increase in this stock has between a 1.7 per cent and 3.7 per cent increase in output, which concurs with estimates from aggregate samples.

Results for the presence of the equipment spillover are highly convincing even at the disaggregated level, as with the aggregate samples. All industries, with the exception of Electrical Machinery, have a positive and significant coefficient on this spillover. Several industries, for instance, Chemicals, Electronics and Non-Electrical Machinery, have a very high coefficient on this spillover. This might be because, the proportion of skilled workers employed in these industries is very high. Greiner and Semmler (2002) point out, that the spillover from physical capital has ameliorated effects for those firms, whose workforce has a high proportion of skilled workers. This is because, such workers are better able to assimilate information generated from their contemporaries. Preliminary investigation of the data shows that the ratio of skilled to unskilled workers in these industries is 0.47, 0.55, and 0.51 respectively, which is higher relative to the average of 0.33 of all industries combined.

Specification 2 presents results of regressions using data on conventional inputs, own R&D and its spillover. These results, unlike for aggregate samples, do not provide convincing evidence, that R&D has a significant impact on a firm's output. Only three industries, Base Metals, Rubber & Plastic and Food, are found to have a significant coefficient on R&D. One possible explanation for the insignificant R&D coefficient across industries is that, since the proportion of firms investing in R&D within these industries is low, data aggregated over all firms does not reflect the true impact of R&D. Therefore, regressions were re-run for all industries considering only the R&D sample of firms. However, not much improvement was observed. Another possible cause of the insignificant R&D coefficient, is the double counting problem, cited in Los and Verspagen (2000). This problem, as the name suggests, arises because, the conventional inputs of a firm are counted twice; once as inputs used in the production process, and then again, as part of those R&D expenditures, which are attributable to these inputs. This leads to a downward bias in the R&D coefficient. To avoid double-

counting, it is necessary to have data on wages, purchases of materials and investment in capital, which is bifurcated, based on the use of these inputs in production and R&D facilities. This type of firm-level data is hard to locate for any country. However, Prowess mitigates this issue, by segregating the total R&D expenditure of a firm into the current and capital account. The former type of expenditures includes salaries to workers and purchase of materials associated with R&D, whereas the latter includes investments in physical capital for R&D purposes. To verify if double-counting is the cause of the insignificant R&D coefficients, instead of constructing the R&D stock of a firm using its total R&D expenditures, it is constructed using R&D expenditures on the current and capital account separately. Two separate regressions are re-run for all industries, after constructing the R&D stock from expenditures of both types respectively. The results are displayed against the column on R&D – current and R&D – capital in **Error! Reference source not found.** It can be observed, that whereas Miscellaneous Manufacturing and Leather, also show a positive and significant coefficient using the R&D stock created from current expenditures, Electrical Machinery and Paper show a positive and significant coefficient, when using the stock created from capital expenditures. Therefore, it can be inferred, that double counting leads to a bias in the R&D coefficient, and accounting for it, alleviates the problem to a certain extent. Seven out of fourteen 2-digit industries display a significant R&D coefficient constructed using either of the three types of R&D expenditures. However, when considering the stock using capital expenditures, it is observed that Chemicals has a negative and significant R&D coefficient. It must be remembered though, that constructing R&D stock using either of these expenditures, only partially corrects for double-counting without solving it completely.

Nonetheless, it is interesting to note, that a few industries for which, the coefficient on the R&D stock (created from either the total, capital, or current expenditures on R&D), is significant, are more export-orientated relative to others, as reported in . For instance, Base Metals, Rubber & Plastic and Leather, have a significant and positive coefficient on one of the R&D stocks, and are also relatively more export-orientated relative to other industries. It can be inferred from this, that R&D has been instrumental in helping these industries increase their exports. Hasan and Raturi (2003) also concluded using firm-level data from Indian manufacturing, albeit for the period 1988 to 1990, that investing in R&D facilitates firms' exports.

Turning to the effects of the R&D spillover, it can be seen that all industries benefit greatly from it. Technological-intensive industries, gain more from this spillover, relative to non-

technological-intensive ones. The elasticity of this spillover ranges from 17.2 per cent for Chemicals to 39.43 per cent for Electronics and 45.6 per cent for Miscellaneous Manufacturing, each of which are technological-intensive industries. It is also worth noting, as with the aggregated samples, that the estimated elasticity of the spillover is much larger, compared to the R&D coefficient. Electrical Machinery and Leather are the only two industries, which have an insignificant coefficient on this spillover. This study finds no presence of “creative destruction” (Aghion and Howitt 1992) within Indian industries, whereby strongly R&D-intensive firms force their competitors out of the market, which would have ensued in a negative coefficient on the R&D spillover. On the other hand, most industries gain significantly from this spillover.

## **5. Implications of findings and concluding remarks**

Economists have raised growing concerns lately, over the decreasing intensity of investments, and slower than expected growth rates, in Indian manufacturing over the latter half of 1990s. In this context, to underscore the salience of investment in equipment and R&D for Indian manufacturing, this research finds that, not only do knowledge generated by a firm’s internal efforts, but also, intra-industry spillovers generated through all other firms’ investment efforts, favourably affect the output of a firm. As noted before, these findings add considerable value to the literature, as previous studies on India, had not found a firm’s own R&D’s contribution to be significant. Moreover, no studies till date, have evaluated the impact of spillovers from the industry-wide equipment stock.

The analysis suggests that the recently purchased equipment stock of a firm favourably affects output. This stock may comprise domestically purchased and/or imported machinery. Since the latest machinery embodies contemporary technology, it is suggested that firms, including India’s large number of labour-intensive firms, should ensure that their equipment stock incorporates the latest design and technology. However, a recent change in the Indian Government’s Foreign Trade Policy, defeats this claim, at least with respect to the import of machinery. As of August, 2004, firms were once again allowed to import second-hand machinery of any vintage. The importation of second-hand capital goods, which may incorporate outdated technology, may retard the competitiveness of Indian firms in the world market and dampen exports.

There is strong evidence linking a firm's productivity to the learning by doing effects from investments in equipment, made by all other firms. This further underscores the need for using equipment of a new vintage, which would positively affect the output of all firms in that industry. Furthermore, this spillover suggests that a firm enjoys the level of development effects of the industry to which it belongs. All firms gain from this spillover. A firm need not be large in size or investing heavily in either equipment or R&D to benefit from this spillover. However, its effect is found to be higher for a firm which employs more skilled workers. In a labour-abundant country such as India, the need for training the workforce therefore, assumes even more significance.

This research also finds, that a firm's own R&D, makes a significant contribution to output, at least when considering the aggregated samples. This claim holds true, even for disaggregated samples, if the double-counting problem is alleviated. It is also interesting to note that several industries, which gain from R&D, are export-orientated. Furthermore, not only does R&D help a firm build its own stock of knowledge, it also exerts a significant positive externality onto other firms within the same industry, including labour-intensive industries. It appears from these results, that India's manufacturing output is being increasingly knowledge driven. Promoting investments in R&D may transform India's merchandise export structure from being resource-based to low- and medium-technology-based. It is gratifying to note the steadfast efforts of the Government of India in this direction. Even if small- and medium-sized firms cannot afford independent research, the possibility to organise cooperative R&D facilities is worth considering. Kumar and Aggarwal (2005) find that R&D intensity in India, when considering only small-sized firms, declines with firm-size. Therefore, such firms can consider cooperative R&D, which would benefit all of them as well as others in the industry. Medda *et al.* (2006) have gathered evidence from Italy that such collaborative research yields high returns to firms.

The findings of this research suggest that output of an Indian manufacturing firm is being increasingly driven by knowledge stocks and spillovers, over the period 1994 to 2006. Therefore, to sustain growth, it is imperative that equipment be modernised and that R&D opportunities explored. Such investments can bolster the performance of Indian manufacturing, and can help it become, yet again, one of the engines of growth for the entire Indian economy.

## Acknowledgements

Helpful comments and suggestions from Mita Bhattacharya, Jakob B Madsen and Russell Smyth, and the participants at the Department of Economics Workshop of Monash University, are gratefully acknowledged.

## References

- Aghion, Philippe and Peter Howitt (1992). "A model of growth through creative destruction." Econometrica **60**: 323-351.
- Balakrishnan, Pulapre and M Suresh Babu (2003). "Growth and distribution in Indian industry in the nineties." Economic and Political Weekly: September 20. 3997 - 4005.
- Baltagi, Badi H and Ping X Wu (1999). "Unequally spaced panel data regressions with AR(1) disturbances." Econometric Theory **15**: 814-823.
- Basant, Rakesh and Brian Fikkert (1996). "The effects of R&D, foreign technology purchase, and domestic and international spillovers on productivity in Indian firms." Review of Economics and Statistics **78**: 187-200.
- CSO, Central Statistical Organization (1989). Sources and methods, Chapter 22: Capital stock and consumption of fixed capital, National Accounts Statistics, Government of India.
- CSO, Central Statistical Organization (2006). National Accounts statistics, Ministry of Statistics and programme implementation, Government of India.
- DeLong, Bradford and Lawrence Summers (1991). "Equipment investment and economic growth." Quarterly journal of Economics **106**: 445-502.
- Department of Commerce (2007). Foreign Trade Policy. Ministry of Commerce & Industry. Government of India.
- Frankel, Marvin (1962). "The production function in allocation and growth: a synthesis." American Economic Review **52**: 995-1022.
- Greenwood, Jeremy, Zvi Hercovitz and Per Krussell (1997). "Long-run implications of investment-specific technological change." American Economic Review **87**: 342-362.
- Greiner, Alfred and Willi Semmler (2002). "Externalities of investment, education and economic growth." Economic Modelling **19**: 709-724.
- Griliches, Zvi (1979). "Issues in assessing the contribution of research and development to productivity growth." The Bell Journal of Economics **10**: 92-116.
- Hammond, Peter J and Andres Rodriguez-Clare (1993). "On endogenizing long-run growth."

- Scandinavian Journal Of Economics **95**: 391-425.
- Hasan, Rana (2002). "The impact of imported and domestic technologies on the productivity of firms: panel data evidence from Indian manufacturing firms." Journal of Development Economics **69**:23-49.
- Hasan, Rana and Mayank Raturi (2003). "Does Investing in Technology Affect Exports? Evidence from Indian Firms." Review of Development Economics **7**: 279-293.
- Im, Kyung So, Hashem M. Pesaran and Yongcheol Shin (2003). "Testing for unit roots in heterogeneous panels." Journal of Econometrics **115**: 53-74.
- Kalirajan, Kaliappa and Shashanka Bhide (2005). "The post-reform performance of the manufacturing sector in India." Asian Economic Papers **3**: 126-157.
- King, Mervyn A and Mark H Robson (1993). "A dynamic model of investment and endogenous growth." Scandinavian Journal of Economics **95**: 445-466.
- Kumar, Nagesh and Aradhna Aggarwal (2005). "Liberalization, Outward Orientation and In-House R&D Activity of Multinational and Local Firms: A Quantitative Exploration for Indian Manufacturing." Research Policy **34**: 441-460.
- Los, Bart and Bart Verspagen (2000). "R&D spillovers and productivity: Evidence from U.S manufacturing micro-data." Empirical Economics **25**: 127-148.
- Maddala, G S and Shaowen Wu (1999). "A Comparative Study of Unit Root Tests with Panel Data and a New Simple Test." Oxford Bulletin of Economics and Statistics **61**: Special. 631-52.
- Medda, Giuseppe, Claudio Piga and Donald S Siegel (2006). "Assessing the Returns to Collaborative Research: Firm-Level Evidence from Italy." Economics of Innovation and New Technology, **15**: 37-50.
- Nelson, Richard R (1964). "Aggregate production functions and medium range growth projections." American Economic Review **54**: 575-606.
- Office of the Economic Adviser, Ministry of Commerce and Industry (2000). Wholesale price index (WPI) data (1993-94=100), Government of India.
- Panagariya, Arvind (2007). "Why India Lags Behind China and How It Can Bridge the Gap." World Economy **30**: 229-248.
- Raut, Lakshmi K (1995). "R&D spillover and productivity growth: evidence from Indian private firms." Journal of Development Economics **48**: 1-23.
- Romer, Paul M (1986). "Increasing returns and long-run growth." Journal of Political Economy **94**: 1002-1037.
- Romer, Paul M (1990). "Endogenous technological change." Journal of Political Economy **98**:

71-102.

Rosenstein-Rodan, P N (1943). "Problems of industrialization of Eastern and South-eastern Europe." The Economic Journal **53**: 202-211.

Sakellaris, Plutarchos and Daniel J. Wilson (2004). "Quantifying embodied technological change." Review of Economic Dynamics **7**: 1-26.

Shaw, G K (1992). "Policy implications of endogenous growth theory." The Economic Journal **102**: 611-621.

Terleckyj, Nestor N (1974). Effects of R&D on the productivity growth of industries: an exploratory study. Washington D.C, National Planning Association.

Uchikawa, Shuji (2001). "Investment boom and underutilization of capacity in the 1990s." Economic And Political Weekly: August 25. 3247 - 3253.

Wieser, Robert (2005). "Research and development productivity and spillovers: empirical evidence at the firm level." Journal of Economic Surveys **19**: 587-621.

Wooldridge, Jeffrey M. (2002). Econometric analysis of cross section and panel data. Cambridge MA, MIT Press.

www.indiastat.com (2006). Annual Survey of Industries.