R&D spillovers across the supply chain

Madhuri Saripalle (Madras School of Economics)

This study attempts to capture the impact of R&D spillovers across the supply chain in the automotive industry in India. Though firms may belong to the same industry, the impact of industry level factors may vary across different levels of the supply chain within the industry. The automobile industry is a good case in point: though auto component firms belong to the automobile sector, they come under diverse industrial classification schemes like rubber, electronics and engineering. The present study attempts to measure the spillovers within the auto components Industry as well as spillovers coming vertically from the original equipment manufacturers (OEM) from a flow and a stock perspective. The trend in R&D expenditures undertaken by various component types suggests that most of the R&D occurs in the engine, suspension and tyre category indicating the adaptive nature of R&D, given India's infrastructure. The study finds spillovers from within the component group are a substitute for firm's own in-house R&D, while spillovers coming from outside the component group act as complements, thus indicating the integral nature of automobile design, requiring collaborative R&D effort. Among the OEMs, spillovers vary based on vehicle category suggesting that nature of OEM-supplier collaboration differs by vehicle types.

Madhuri Saripalle (Assistant Professor)

Madras School of Economics, Chennai.

JEL classification codes: L6 (Industry studies), L22 (Industrial Organization), O33 (Technological change/R&D)

Key words: Industry studies, Research & Development, Country studies, Industrial Organization, Supply chain

R&D spillovers across the supply chain

I. Introduction

Spillovers are an important source of growth and learning of firms. Spillovers can take place via foreign direct investment, research and development activities and various other ways. Among these, of particular interest is, Research and Development (R&D) spillovers, which create an externality. In other words, the nature of knowledge externality implies that firm receives for free or at relatively low price knowledge which other firms have generated. This is a classic case of market failure resulting in a divergence between private and social marginal cost of R&D. Since producers of knowledge cannot realize the full social return to their efforts if such externalities exist, private incentives for the production of knowledge are distorted and firms are likely to under-invest in R&D efforts. Hence, it is important to capture the impact of R&D by a firm on other firms in terms of both direction and magnitude.

Knowledge spillovers are typically captured by measuring the distance between firms in terms of R&D expenditures (measured by the difference between the total industry R&D and a firm's own stock of R&D), or through the use of patent data. Substantive literature has been published on measuring the R&D spillovers using different datasets and control variables. Studies measuring spillovers typically capture the inter-industry differences, rather than intra-industry differences, as the pool of accessible knowledge will be the same across a cross section of firms within an industry (Grilliches, 1994). R&D spillover may be a substitute or complement to the firm's own knowledge depending on the absorptive capacity of firms. In case it is a substitute, then, controlling for the level of output, we should observe a negative effect of spillovers on the firm's R&D expenditures.

Spillovers across the supply chain have been widely studied in the context of foreign direct investment and the transfer of technology by multinationals to domestic suppliers (Blalock and Gertler, 2007; Javorcik 2004; Aitken and Harisson 1999). The study by Aitken et al (1999) does panel data analysis to show that intra-industry FDI spillovers are limited; while joint venture firms benefitted from foreign equity participation, the spillover from joint venture plants to plants with no foreign investment was negative. Subsequently, other studies (Kuger, 2006) have found that FDI spillovers are more prominent between industries than within industries.

The present study attempts to capture the impact of R&D spillovers across the supply chain in the Indian automotive industry. The automobile industry is chosen because of the presence of a well structured and lengthy supply chain spanning across various industries. Suppliers in the automotive industry which can be categorized in diverse industries based on the national industrial classification (NIC) code. In this way, though auto component firms belong to the automobile sector, they come under diverse industrial classification schemes, including rubber (example tyres), electrical (battery and storage), automobile parts (suspension, transmission and engine components) and domestic appliances (air conditioning systems). Hence spillovers to auto component firms in this case come across a wide range of industries. Further, the nature of spillovers may be complementary or substituting depending on the degree and extent of collaboration among suppliers.

The study differs from the previous studies in the following ways. It measures the impact of R&D spillovers within the component subgroup, between the component subgroups and from the upstream firms consisting of the OEMs. In the context of a supply chain, horizontal or vertical collaborations within a supply chain can result in a positive impact of spillovers on the firm's own R&D. Section II presents the literature review, followed by section III which outlines the motivation and objectives of the study. Section IV presents the methodology, followed by section V which presents the Data and variables. Section VI presents the results and conclusion.

II. Literature review

Empirical work on R&D spillovers uses two approaches to measure spillovers: firm's R&D effort (R&D expenditure) and; firm's R&D stock. Both the approaches are discussed below.

II.1 Spillovers measured by firm's R&D intensity

Some of the pioneering work in the sphere of R&D spillovers is by Grilliches (1979, 1992) and Cohen & Levinthal (1990, 1992). It was Griliches (1979) who suggested that measures of spillover could be obtained by using indicators of proximity or similarity between firms. According to Cohen et al, absorptive capacity is modeled as a function of other productive R&D

expenditures. As a consequence of this assumption, high spillover rates have two effects. On one hand, they create the R&D disincentives; while on the other hand, the information externalities will induce the firm to step up its own R&D efforts in order to absorb more of the available spillover information. The aggregate effect may well lead firms to respond to higher spillover rates by increasing own R&D spending. The impact of R&D spillovers on cost has been measured by Bernstein (1988) who analyses inter-industry and intra-industry spillovers simultaneously. Spillovers of both types are found to reduce average cost of production. Surprisingly, the effect of inter-industry spillovers appears to be much stronger than that of spillovers within the industry. Furthermore, it appears that inter-industry spillovers are in all cases substitutes for private R&D efforts by firms within the industry. Conversely, intra-industry spillovers are complementary to private R&D efforts for firms operating in industries with relatively large R&D expenditures, while they work as substitutes for private R&D in industries with a low R&D intensity.

Apart from R&D spillovers, studies have identified some of the important variables such as, market structure, technology imports (disembodied technology transfer), FDI, firm size, appropriability conditions, export orientation and outward FDI that impact a firm's own R&D effort. Inter-firm variations are found in R&D behavior of firms depending on size, technology intensity and ownership, across industries. A brief review of these studies is provided below.

Concentration: Faber (1981) finds that industries characterized by both high buyer and seller concentration experienced higher R&D intensities. That is, a combination of oligopsony and oligopoly was most favourable for R&D, which in turn implies better appropriability conditions. In the context of present study, this would mean that buyers and suppliers could benefit through R&D collaboration and appropriate the benefits thereby.

Firm size and market conduct: Advertisement and R&D are jointly determined inputs for the firm. From the point of view of increasing firm demand and creating entry barriers they are complementary inputs. Based on firm level data for a cross-section of industries and firms (1982-85) Siddharthan (1988) analyzes differences in R&D performed by small and large firms. He finds that R&D intensity could fall with size, R&D and firm size 'U' shaped relationship. In another study that captures post-liberalisation period (Aggarwal, 2000), the author finds that R&D spending seems to rise more than proportionally with firm size after a certain threshold level has been reached.

Technology import: Several studies have been done to analyze the impact of technology variables on R&D intensity. Siddharthan (1988), for example finds that R&D and technology imports have a complementary relationship; adaptive R&D complements and not innovative R&D. In another study (1992), the author finds that technology imports and FDI, both have a positive relationship with R&D effort. Aggarwal (2000), in her study of Indian manufacturing Industry analyzes the impact of technology imports on R&D efforts across two policy time frames: protection and deregulation. Her results show that technology imports were only weakly related with the past in-house R&D efforts in the protective regime. Deregulation promoted complementarities between technology imports and R&D efforts significantly. She also finds that post liberalization, local firms direct their R&D activity primarily towards the assimilation of imported technology, and to providing a backup to their outward expansion via exports and FDI. MNE affiliates, on the other hand, focus on exploiting the advantages of India as an R&D platform for their parents.

II.2 Spillovers measured by R&D stock

Harhoff (2000) studies the impact of R&D spillovers on R&D spending and productivity of firm for high technology and low technology intensity firms, using a panel data for German manufacturing firms. He estimates the R&D intensity (R&D spending/ capital stock) as a function of the ratio of lagged R&D spending of firm and capital stock of firm, external spillover of R&D/capital stock and sales/capital stock. He uses a proximity based measure of spillover based on a firm's distribution of R&D expenditure across 34 product categories. He finds that spillovers are stronger in high technology intensity firms with productivity enhancing effects. Consistent with absorptive capacity hypothesis, firms with higher capital stock benefit more from external R&D. In the Indian context, a recent paper by Saxena (2011) finds that technology stocks and spillovers have significantly affected the output of Indian manufacturing firms over the period 1994-2006.

A recent study (Motohashi and Yuan, 2010) compares horizontal and vertical spillovers from multinational to local firms in the Chinese Automobile and Electronics industry They find that while vertical productivity spillovers are present in the automobile industry, they are negligible in case of the electronics industry. The study does not find horizontal spillovers in both the industries. Productivity spillovers are estimated through a Cobb-Douglas production function approach where, the value added is estimated as a function of capital, labor, innovation, spillover variables and market share of firm. R&D capital stock is used as a measure of technology spillover, wherein, the sum of technology stock of assembly and supply sector firms are calculated for local and multinational firms.

II.3 R&D in the context of the automobile Industry

Since Liberalization, there has been a phenomenal growth in R&D effort in the automotive industry in India because of delicensing of industry and the entry of Multinational Enterprises (MNEs); local content requirement by the government, resulting in joint collaborations between MNE OEMs and suppliers; stiff competition and increasing quality standards. Pradhan and Singh (2009) undertake a quantitative analysis of the influence of OFDI activities on the in−house (domestic) R&D performance of Indian automotive firms during 1988–2008. They find that the proportion of automotive firms with above 2 per cent R&D intensity has gone up from 4 per cent of the total number of firms in 2001 to 6 per cent in 2007. A comparison of the average R&D intensity across different segments of Indian automotive sector during 2000–2007 shows that commercial vehicle manufacturers have generally higher R&D intensity followed by two & three wheelers companies, automobile ancillary suppliers, and passenger cars & multi utility vehicles producers in that order. Though the product development capabilities of the OEMs has increased as MNEs shift such activities to India, the R&D intensity of foreign affiliates is much lower than its counterparts abroad (Narayanan and Vashisht, 2008; Singh, 2007). In the auto component sector the R&D is still primarily oriented towards process development.

Pradhan and Singh (2009) estimate a pooled Tobit regression results on the determinants of R&D behaviour of Indian automotive firms. They find that outward FDI is a significant variable and hence outward investing Indian automotive firms are likely to benefit from global knowledge spillovers for doing more in-house R&D as they get proximity to innovation centers and innovative competitors in foreign countries. Other independent variables that are significantly affecting R&D activities of Indian automotive firms include age, size, disembodied technology, export intensity and foreign direct investment all of which have significant positive coefficients.

Much of the evidence in the automobile sector points out to the fact that the R&D in the Indian industry is process- oriented and of an adaptive nature. However, there is also anecdotal evidence and case studies of high-end supplier capabilities and products built out of a high degree of supplier collaborations (Bowonder, 2004). This suggests that R&D spillovers may not be uniform across the automotive supply chain.

The present study attempts to analyze the R&D spillovers in the Indian automobile industry. It differs from previous studies in the following way. Previous literature on Indian automobile industry has not analyzed the spillovers across the supply chain of an industry. Secondly, the present study analyzes spillovers using two specifications, from a flow and a stock perspective. The present study attempts to measure the spillovers within the auto components Industry as well as spillovers coming vertically from the original equipment manufacturers (OEM). As the auto component industry consists of three diverse groups of sectors, namely, engineering, electrical and rubber industries, component firms are categorized into engine, electrical, suspension, transmission, tyres, other and other2 categories.

III. Methodology

Two specifications are used to capture spillovers across the supply chain: one uses R&D intensity as dependent variable with sales as denominator and the other specification estimates spillovers from capital stock.

Spillovers are divided into three categories:

1. Horizontal spillovers coming from within the group (for example, engine): Spillovers from within the group are measured by subtracting the R&D expenditures of the firm from the total R&D expenditures of the component group it belongs to. The coefficient sign in this category is expected to be negative, that is, R&D spillovers within the group are expected to be a substitute for own firm R&D.

2. Horizontal spillovers outside the group (for example, if the firm belongs to engine category, this variable captures spillovers from, say, suspension category): Spillovers from outside the group are measured by subtracting the R&D expenditures of a component group from the total R&D expenditures of the component industry for a particular year. The coefficient sign in this category is expected to be positive, suggesting that firms may be encouraged to increase own R&D if the other component groups have also increased R&D. This may be due to the integral nature of an automobile, wherein there is interdependency between various modules of a vehicle. Hence any innovation in one module would require a corresponding innovation in the other module.
3. Vertical spillovers from the OEMs: Spillovers from automotive manufacturers are measured by the R&D expenditures by the respective manufacturers. The coefficient sign of this category could be positive or negative depending on the nature of collaboration and capability within the supply chain.

There is a high degree of correlation among the spillover categories, hence the spillovers were captured separately in different model specifications.

Model 1: Spillovers from R&D intensity

The following relationship is estimated:

$R/S = \alpha_{it} + \beta_{1t} R_{it-1}/S_{it-1} + \beta_{2t} R_{-it}/S_{it} + \beta_{3t} R_{jt}/S_{it} + \beta_{4t} R_{oem}/S_{it} + \beta_{5t} Dtech/S_{it} + \sum\beta_{it} X_{it}$

Where the subscripts i and j refer to, firm within a component group and firms outside the component group respectively. The subscript –i refers to firms other than the i^{th} one within the same component group.

- R_{it-1}/S_{it-1} consists of lagged R&D expenditures of firm i within a component group/sales.
- Horizontal spillover from within the group is measured by R_{-it}/S_{it} which consists of R&D expenditure of firms other than the i^{th} firm within the component firm divided by sales of firm i. That is, if firm i belongs to engine category, it captures the R&D of all firms in the engine category other than firm i.
- Horizontal spillover from outside the group is measured by R_{jt}/S_{it} ,which consists of R&D of firms outside the component firm's category/sales of firm i. That is, if firm i belongs to

the engine category, this variable captures the R&D of all firms belonging to categories other than the engine category.

- Vertical spillovers are captured by R_{oem}/S_{it}, that consists of R&D of OEM firms/Sales of firm i.
- Dtech represents disembodied technology in the form of royalties and licensing fees paid to acquire technology.The variable is divided by sales to arrive at technology intensity.
- X_{it} represents control variables consisting of number of employees and Herfindahl index.

Model 2: Spillovers from R&D capital stock

Capital stock is obtained by the perpetual inventory method with a discount rate of 15%.

$R_{i2002} = \sum_{t=0}^{5} Rexp_{i,\ 2001-t} (1-\delta)^{t}$

Stock for subsequent years is calculated by: $R_{i,t+1} = R_{it} (1-\delta) + RDexp_{it}$

The capital stock for 2002 was obtained by summing across the discounted R&D expenditures for the past five years (1996-2001) after deflating them by the appropriate price index.

The following relationship is estimated:

- $R/S = \alpha_{it} + \beta_{1t} R_{-it}/S_{it} + \beta_{2t} R_{jt}/S_{it} + \beta_{3t} R_{oem}/S_{it} + \beta_{4t} Dtech/S_{it} + \sum\beta_{it} X_{it}$
- Horizontal spillovers within group: R_{-it}/S_{it} consists of capital stock of firms within the component firm/sales of firm i
- Horizontal spillovers outside group: R_{-jt}/S_{it} consists of capital stock of firms outside the component firm's category/sales of firm i
- Vertical spillovers: R_{oem}/S_{it} consists of capital stock of OEM firms/sales of firm i.
- Dtech represents disembodied technology in the form of royalties and licensing fees paid to acquire technology.
- X_{it} represents control variables consisting of number of employees and Herfindahl index.

IV. Data and description of variables

Data is obtained from CMIE's Prowess database consisting of more than 500 firms in the automotive sector. A sample of 241 auto component firms and 36 firms (comprising of two, three and four wheelers) was used across the ten year period of 2002-2011. The diversified firm category consisted of only two firms: Bajaj Automobiles and Mahindra and Mahindra. It was dropped in the estimation as it is an outlier because of its high R&D expenditures as well as fewness of firms.

Table 1: Component Classification

Component Group	No. of Firms
Engine	47
Electrical	20
Suspension	33
Transmission	32
Sheetmetal	14
Tyres	27
Other_2	41
Other	30

Table 1a: OEM group classification

OEM group	No. of firms
Commercial Vehicles	9
Diversified Automobiles	2
Passenger Cars	9
2/3 wheelers	15

Tables 1/1a show the number of firms in each category of component and OEM group. A more detailed break up of the type of firms classified under each component group is given in the appendix. Table 2 shows the descriptive statistics for the same during the ten year time period

R&D: R&D expenditure broadly comprises expenditure on equipment, plants and machinery and salaries of R&D personnel. Price changes in these two components would be different over a period of time and the most suitable price deflator would be a composite index covering price changes in capital equipment and salaries component. Price index for capital equipment is given by the WPI for machinery and machine tools, whereas, price index for R&D personnel can be taken from the CPI for industrial workers reported by the ministry of labor. Saxena (2011) uses an average of the two indices to arrive at a deflated measure of R&D expenditures.

In the present study, the R&D expenditures are deflated by the WPI for capital equipment (machine and machine tools) for the respective years before calculating the stock. The data was obtained from the office of economic advisor[1]. Figures 1-4 show the R&D expenditure and stock for auto component suppliers and OEMs. The trend is highest for engine, suspension, tyres and other2 components.

[1] http://eaindustry.nic.in/wpi_data_display/display_data.asp

Table 2: Descriptive statistics

Descriptive statistics of auto component subgroups over the period 2002-2011									
	Engine	Electrical	Suspension	Transmission	Sheet metal	Tyres	Other2	Other	No. of fims
Mean Values									
R&D intensity	0.010	0.011	0.009	0.010	0.003	0.002	0.009	0.010	88
Technology Int	0.006	0.002	0.005	0.002	0.000	0.001	0.005	0.005	88
Hindex	0.191	0.178	0.077	0.088	0.168	0.145	0.078	0.072	119
employees	2587	2984	1573	1049	411	5484	1817	966	119
Ownspill_int	1.72	0.42	0.38	0.36	0.00	0.25	0.30	0.21	88
Groupspill_int	4.34	4.10	1.52	5.78	2.06	1.51	2.00	2.95	88
Firmsales_defl	2413	5530	2725	1702	568	11677	3718	1631	119
Standard Deviation									
R&D intensity	0.01	0.01	0.01	0.02		0.00	0.01	0.01	88
Technology Int	0.01	0.00	0.01	0.00		0.00	0.01	0.01	88
Hindex	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	119
employees	6968	3881	1938	1471	830	6213	2310	961	119
Ownspill_int	3.06	0.59	0.38	0.73		0.64	0.42	0.24	88
Groupspill_int	7.61	5.61	1.45	11.56		3.75	2.52	3.05	88
Firmsales_defl	6083	7584	3117	2448	1152	14189	4977	1709	119
Minimum									
R&D intensity	0.001	0.001	0.000	0.000	0.003	0.000	0.001	0.001	88
Technology Int	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	88
Hindex	0.19	0.18	0.08	0.09	0.17	0.15	0.08	0.07	119
employees	0	36	0	0	0	114	0	28	119
Ownspill_int	0.009	0.012	0.036	0.014	0.000	0.007	0.023	0.031	88
Groupspill_int	0.082	0.138	0.200	0.344	2.060	0.064	0.184	0.551	88
Firmsales_defl	0.00	34.90	0.00	0.00	0.00	0.00	0.00	12.16	119
Maximum									
R&D intensity	0.03	0.03	0.03	0.06	0.00	0.01	0.04	0.039	88
Technology Int	0.02	0.01	0.02	0.01	0.00	0.00	0.03	0.033	88
Hindex	0.19	0.18	0.08	0.09	0.17	0.15	0.08	0.072	119
employees	33058	11026	7803	5681	1397	18172	7927	3204	119
Ownspill_int	12.50	1.63	1.48	2.59	0.00	2.09	1.46	0.817	88
Groupspill_int	31.17	15.56	5.76	41.63	2.06	12.08	8.65	10.562	88
Firmsales_defl	29610	22906	13372	9158	1945	42914	18128	5934	119
The data includes only firms which had R&D>0 in any year. Firms which had nil R&D expenditure were dropped; Source: Prowess database									

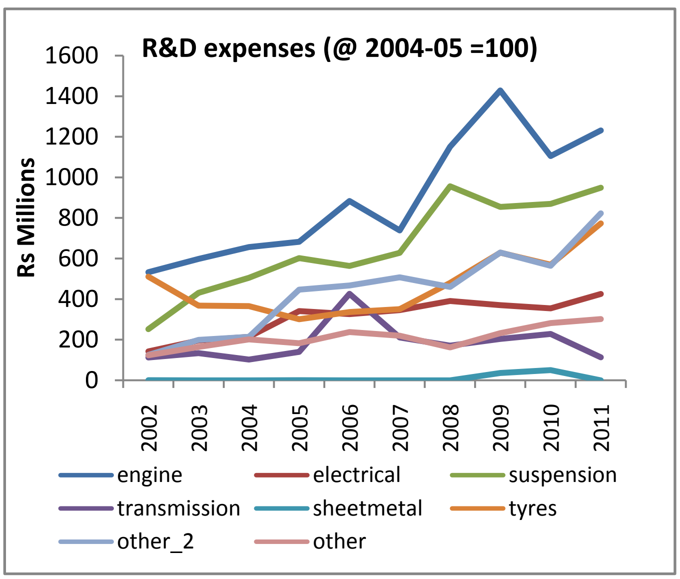
Employees: Data on employees was not available in Prowess for all years. Hence it was estimated by using the data on average emoluments per employee from Annual survey of industries for the respective NIC classifications. The data on wages and salaries was divided by the average wage to arrive at number of employees for each firm. The data on wages and salaries for some firms was not available for all years, hence the number of employees is zero for some firms.

Sales: The annual sales was deflated by CPI (IW) to arrive at sales measured at constant 2001-02=100 prices. The CPI (IW) was obtained from RBI's database.

Technology intensity: Expenditure on royalties and license fees was used as a measure of disembodied technology imports. This was deflated by the WPI for capital equipment for respective years.

Concentration: Herfindahl index was calculated for each of the firm for all years. H-index takes into account the market share of each firm and is a better measure than CR-4 as it takes into account relative sizes of firms in calculating the level of concentration.

Figure 1: R&D expenses of auto component groups **Figure 2: R&D stock of autocomponent groups**



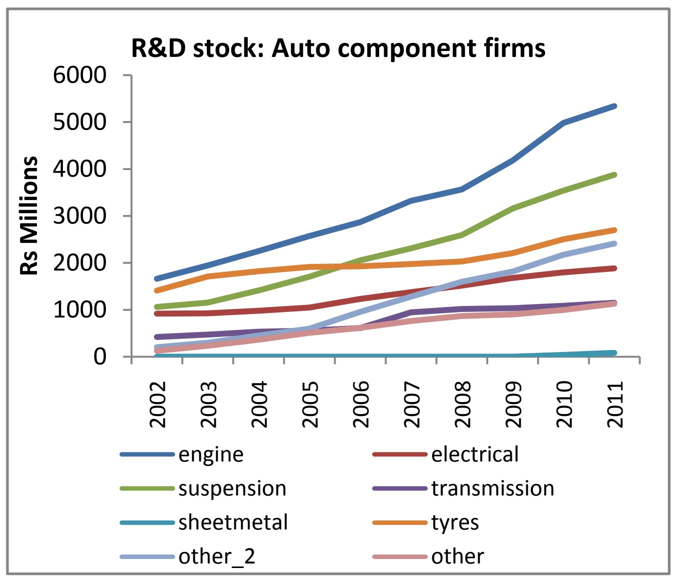


Figure 3: R&D expenses of auto OEMs

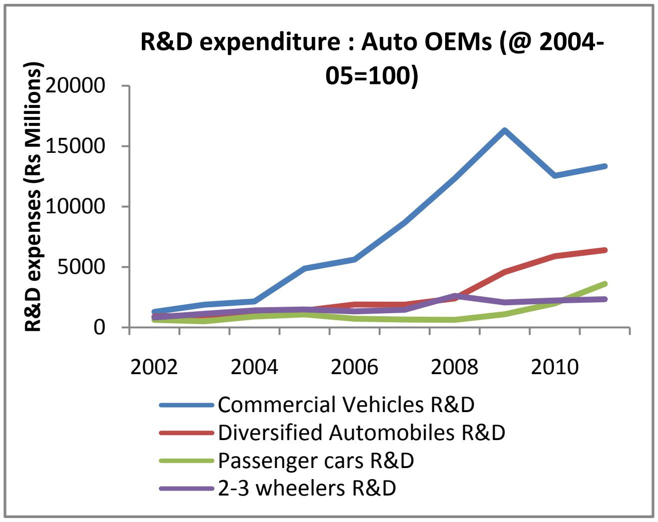
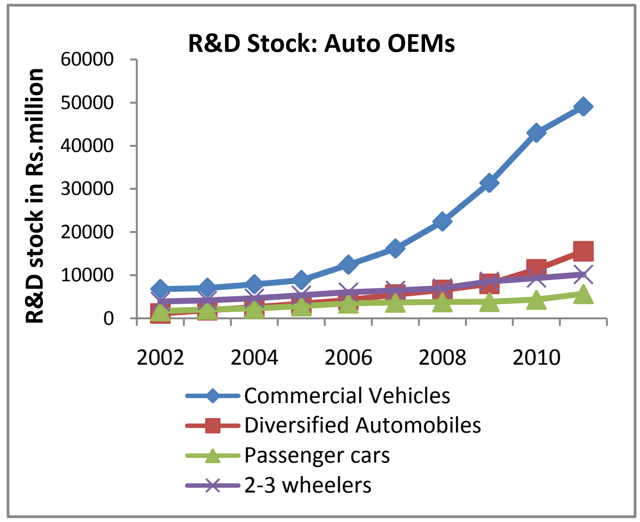


Figure4: R&D stock of Auto OEMs



V. Results and discussion

a. Spillovers from R&D expenditures

From table 3, correlation among the explanatory variables is high. For example, the correlation between R&D expenditures of commercial vehicles and spillover from R&D expenditures of component groups (outside group R&Dspill) is 0.97. There is high correlation among R&D of commercial vehicles and two and three wheelers (0.98).

Table 3: Correlation

	R&D intensity _firm	Lagged_R&D intensity_firm	Within Group_ spill_int	Outside Group_ spill_int	Technology _int	Commercial Vehicle RD_int	Diversified firmRD_int	Passenger car RD_int	Two-three wheeler RD_int	H-index	Employees
R&D intensity_firm	1										
Lagged_R&D intensity_firm	**0.45**	1									
Within Group_spill_int	-0.02	-0.017	1								
Group_spill_int	-0.02	-0.017	**0.95**	1							
Technology_int	**0.1**	**0.08**	-0.025	-0.025	1						
Commercial Vehicle RD_int	-0.018	-0.017	**0.96**	**0.97**	-0.023	1					
Diversified firmRD_int	-0.017	-0.014	**0.97**	**0.95**	-0.022	**0.97**	1				
Passenger car RD_int	-0.018	-0.014	**0.96**	**0.92**	-0.023	**0.91**	**0.98**	1			
Two-three wheeler RD_int	-0.02	-0.017	**0.98**	**0.98**	-0.026	**0.98**	**0.97**	**0.95**	1		
H-index	-0.043	-0.036	-0.01	-0.001	**-0.067**	-0.005	-0.006	-0.006	-0.006	1	
Employees	**0.15**	**0.14**	**-0.027**	-0.026	**0.055**	-0.025	-0.024	-0.024	-0.027	0.098	1

Table 4 shows the Hausman statistics and the model estimations from fixed versus random effects regression. Since Hausman test was not significant, the study adopted a random effects model for estimation. Table 5 shows the results for random effects regression estimates, with different specifications of the model, corrected for autocorrelation and heteroskedasticity. The last row of the table shows results from Woolridge test for autocorrelation in the panel data.

Column (1) shows results from the basic model wherein the spillovers within the outside the auto component groups is estimated along with control variables like firm size, technology spillover and market concentration.

Column (2) shows the estimates from Feasible Generalized Least Square Regression (FGLS) regression, wherein, panels are corrected for heteroskedasticity and auto correlation. The coefficient signs are same in both results, the only difference being that employees is not significant in the first column. Own firm spillover (Lagged R&D exp) is positive and significant; implying that past R&D expenditures increase the absorptive capacity of the firm and are complementary to firm’s current R&D expenses. However, R&D within the component group acts as substitutes to own firm R&D. Spillovers from outside the component group are complementary to firm's R&D expenditures.

In column (3) spillovers from OEMs are also included. Results show that these vary across the vehicle category. Spillovers from commercial vehicle industry are complementary to own firm R&D; whereas, spillovers from passenger car sector is a substitute for own firm R&D. Column (4) shows results from FGLS. These results support the study by Faber(1981) that shows that buyers and suppliers benefit by collaborating with each other. Although Herfindahl index is low for the component industry and is not significant in any of the results, the results indicate that some suppliers may benefit from vertical collaborations.

Table 4: Fixed effects vs.Random Effects

	Fixed Effects		Random Effects	
R&D intensity (R&D/sales)	Coef.	Std.Err.	Coef.	Std.Err.
Outside group R&D spill (R&D/sales of firmi)	0.98	0.088	1.115	0.068
Within group Spillover	-2.53	0.537	-2.971	0.419
Hindex	-0.026	0.0212	-0.007	0.014
Employees	-0.00026	0.000324	0.0001	0.00017
Technology intensity (expenses on know-how/sales of firmi)	0.112	0.086	0.14	0.07
_cons	0.011	0.0024	0.002	0.00172
N	879		879	
Rsq	0.2191		0.2599	
Hausman: Prob>chi2=0.0622				

Table 5: Results from Random Effects Estimation

Dependent Variable: R&D intensity	Col (1) RE (not corrected for Autocorrelation & Heteroskedasticity)	Col (2) RE (corrected for Autocorrelation & Heteroskedasticity)	Col (3) RE (not corrected for Autocorrelation & Heteroskedasticity)	Col (4) RE (corrected for Autocorrelation & Heteroskedasticity)
Within goup spillover	-0.003 (0.0015)**	`-0.0017 (0.0002)***	`-0.0012 (0.0007)*	-0.0009 (0.0004)**
Outside group spillover	0.001 (0.0004)***	0.0005 (0.0000)***	0.002 (0.0009)**	0.0005 (0.0001)**
Employees	0.0000 (0.0000)	0.0000 (0.0000)***	0.0000 (0.0000)	0.0000 (0.0000)***
Hindex	-0.008 (0.013)	0.003 (0.002)	0.0067 (0.01)	0.0038 (0.003)
Tech_int	0.141 (0.064)**	0.16 (0.019)***	0.134 (0.06)**	0.12 (0.024)***
Lag R&D intensity			0.38 (0.17)**	0.313 (0.03)***
Commercial Vehicle R&D			0.0003 (0.0002)	0.00007 (0.00003)**
Passenger Car R&D			-0.004 (0.00015)**	-0.0006 (0.0002)***

Two/three wheeler R&D			-0.002 (0.00015)	-0.0002 (0.0002)
_cons	0.007(0.002)***	0.0067(0.0003)***	0.001 (0.007)***	0.0037 (0.0005)***
N	879	833	879	833
Rsq	0.26		0.44	
Woolridge test for Autocorrelation in Panel data	H0: no first-order autocorrelation F(1, 111) = 3.398 Prob > F = 0.0679		H0: no first-order autocorrelation F(1, 111) = 9.352 Prob > F = 0.0028	
Figures in Parenthesis are standard errors. *significant at <10% level; **significant at < 5% level ; *** significant at < 1% level				

b. Spillovers from R&D capital stock

Tables 6 shows the results for Hausman test for the second specification of spillovers, from R&D capital stock. The results show that fixed effects is better fit than random effects model, contrary to the first model. The results from fixed effects model are presented in table 7. Column (1) shows estimates of spillovers from within the component sector, excluding the spillovers from vehicle manufacturers. Column (2) shows spillovers only from the vehicle manufacturers and not from within the component sector. Column (3) shows the overall result including all variables. The explanatory power of the model is very low as indicated by the R square. The variables that emerge significant within and outside group spillovers, which have the same coefficient signs as the results from the previous model.

In the second column, spillovers from commercial and passenger car segment have a negative impact, but those coming from two/three wheeler have a positive impact on the R&D of the firm. When all the variables are included, the coefficient on within group spillovers changes to positive. Herfindahl index also emerges positive and significant.

Table 6: Fixed versus Random Effects for R&D stock spillovers

	Fixed Effects		**Random Effects**	
R&D intensity (R&D/sales)	Coef.	Std.Err.	Coef.	Std.Err.
Within group R&D spill (R&Dstock /sales of firmi)	-0.382	0.22	-0.74	0.15
Outside group R&D spill (R&Dstock /sales of firmi)	0.18	0.031	0.28	0.022
Hindex	-0.033	0.022	-0.008	0.014
Employees	-0.0002	0.0003	0.0001	0.0002
Technology intensity	0.115	0.09	0.14	0.07
constant	0.012	0.002	0.007	0.002
N	879		879	
Rsq	0.15		0.215	
Hausman: Prob>chi2=0.000				

Table 7: Fixed Effects estimation for R&D stock spillover

Dependent Variable: R&D intensity	Col (1)	Col (2)	Col (3)
Within group spillover	`--.0004 (0.0015)***		0.0016 (0.0004)***
Outside group spillover	.0002 (0.0004)*		0.0011 (0.0003)***
Employees	0.0000 (0.0000)	0.0000 (0.0000)	0.0000 (0.0000)
Hindex	` -.034 (0.013)	0.031 (0.021)	0.039 (0.021)**
Tech_int	.1155 (0.09)	.046 (0.082)	0.042 (0.081)
Commercial Vehicle R&D		-0.00028 (0.00025)***	-0.0004 (0.0004)***
Passenger Car R&D		-0.0032 (0.00038)***	-0.005 (0.0005)***
Two/three wheeler R&D		0.0029 (0.0002)***	0.002 (0.0003)***
_cons	.012 (0.002)***	0.003 (0.002)	0.002 (0.002)
N	879	879	879
Rsq	0.15	0.08	0.04
Woolridge test for Autocorrelation in Panel data	H0: no first-order autocorrelation F(1, 111) = 4.487 Prob > F = 0.036	H0: no first-order autocorrelation F(1, 111) = 0.26 Prob > F = 0.60	H0: no first-order autocorrelation F(1, 111) = 0.89 Prob > F = 0.34
Figures in Parenthesis are standard errors. *significant at <10% level; **significant at < 5% level ; *** significant at < 1% level			

References

1. Aitekn, B.J., Harison, A.E., 1999. "Do domestic firms benefit from direct foreign investment? Evidence from Venezuela". American Economic Review 89, 605–618.
2. Aggarwal Aradhna (2000), "Deregulation, technology imports and in-house R&D efforts: an analysis of the Indian experience", Research Policy (29), pp:1081-1093.
3. Bernstein Jeffrey & M.Ishaq Nadiri (1989), "Research and Development and Intra-industry Spillovers: An Empirical Application of Dynamic Duality", The Review of Economic Studies, Vol. 56, No. 2 (Apr., 1989), pp. 249-267.

4. Bowonder (2004), “Concurrent engineering in an Indian automobile firm: the experience of Tata Motors”, Int. J. of Manufacturing Technology and Management, 2004 Vol.6, No.3/4, pp.291 – 314.
5. Cohen, W. M. and Levinthal, D. A. (1989): "Innovation and learning: The two faces of R&D", The Economic Journal, 99, 569-96.
6. Griliches, Z. (1994), “The Search for R&D Spillovers”, in: Scandinavian Journal of Economics, Vol 94 (Supplement), pp. 29–47.
7. Harhoff Dietmar (2000), “R&D SPILLOVERS, TECHNOLOGICAL PROXIMITY, AND PRODUCTIVITY GROWTH –EVIDENCE FROM GERMAN PANEL DATA”, Schmalenbach Business Review, Vol. 52, July 2000, pp. 238–260.
8. Javorcik, Beata Smarzynska (2004), “Does Foreign Direct Investment Increase the Productivity of Domestic Firms? In Search of Spillovers through Backward Linkages”, The American Economic Review, Vol. 94, No. 3 (Jun., 2004), pp. 605-627.
9. Kugler, Martin (2006), “Spillovers from foreign direct investment: Within or between industries?”, Journal of Development Economics 80 (2006) 444– 477.
10. Kumar Nagesh, Aggarwal Aradhna (2005), “Liberalization, outward orientation and in-house R&D activity of multinational and local firms: A quantitative exploration for Indian manufacturing”, Research Policy (34), pp:441-460.
11. Motohashi Kazayuki, Yuan Yuan (2010), “Productivity impact of technology spillover from multinationals to local firms: Comparing China’s automobile and electronics industries”, Research Policy 39 (2010) 790–798
12. Saxena Shishir (2011), “Technology and spillovers: Evidence from Indian manufacturing microdata”, Applied Economics, vol. 43, issue 10, pages 1271-1287.
13. Singh Neelam (2012), “Technological Efforts and Global Operations: Indian Auto Component Firms”, working paper.
14. Pradhan, J. P. and Neelam Singh (2009), ‘Outward FDI and Knowledge Flows: A Study of the Indian Automotive Sector’, *International Journal of Institutions and Economies,* 1(1): 155–186.
15. Siddharthan, N. S. (1988): "In-house R&D, imported technology and firm size: lessons from Indian experience", Developing Economies, 26, 212-221.

Appendix

Table A.1: Component groups classification

Engine	**Electrical**	**Suspension**	**Transmission**	**Other**
Automobile engine parts	Electric horns	Air brakes	Gears including crown wheels	Other Automobile ancillaries,nec
Automobile engine parts, nec	Starter motors	Oil seals	Propeller shafts	Other auto lights
Engine	Rotor pumps	Auto hydraulic pneumatic equipment	Wheels for automobiles	Other autopanel instruments/parts
valves	Electrical automobile parts	Axle housing/ front axle assembly	Wheels/wheel rims	Auto headlights
Pistonrings	Separators	Bimetal bearings	Axle shafts	Auto bulbs
Pistons	Wiring harness & parts	Brake assembly	Clutch assembly	Auto castings
Radiators	Lead-acid accumulators	Brake linings	Clutch facings	Airconditioning machines/systems
Carburettors	Storage batteries	Suspension & braking parts	Clutch plates/discs	Automobile equipment
Crankshafts	Software services	Thickwall, thinwall bearings	Drive transmission & steering parts	Automobile locks
Exhaust systems & components		Auto seating systems		Automotive filters
Filter elements,inserts	**Sheetmetal**	Steering gears	**Tyres**	**Other2**
Flywheel magnetos	Auto plastic moulded components	Steering linkages	Tyre treads	Automobile ancillaries
Gaskets	Auto sheetmetals parts	Shock absorbers	Tyre tubes	Automobile ancillaries nec
Leaf springs(Automotive)	Automobile bodies	Auto dashboard instruments	Tyres	
Flywheel ring gears	Bus body	Hydraulic pumps	Tyres & tubes	
Fuel injection equipment			Retreaded & other tyres	
Fuel injection equipment spares			Retreaded tyres	
Valve guides/pushrods			Motor tyres	
Cylinder liners			Cycle tyres	
Water pump assembly			Pressure gauges	
Timing chains				