WORKING PAPER 83/2013

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November 2013

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Price : Rs. 35

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Abstract

This study attempts to capture the impact of vertical and horizontal R and D spillovers across the supply chain. Empirical studies have captured vertical spillovers while finding the role of horizontal spillovers in R and D to be negligible, as the pool of accessible knowledge is the same for a cross section of firms within an industry. However, from a supply chain perspective, though firms may be suppliers to an industry, they belong to different industries themselves; and different tiers of the supply chain. The automobile industry is a good case in point: though auto component firms supply to the automobile sector, they come under diverse industrial classification schemes like rubber, electronics and engineering. The present study attempts to measure the horizontal spillovers within Indian Indian 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 and D expenditures undertaken by various component types suggests that most of the R and D occurs in the engine, suspension and tyre category indicating the adaptive nature of R and D, given India's infrastructure. The study finds spillovers from within the component group are a substitute for firm's own in-house R and D, while spillovers coming from outside the component group act as complements, thus indicating the integral nature of automobile design, requiring collaborative R and D effort. Among the OEMs, spillovers vary based on vehicle category suggesting that nature of OEM-supplier collaboration differs by vehicle types.

Keywords: *Industry studies, Research and Development, Country studies, Industrial Organization, Supply chain*

JEL Codes: *L6, L22 , O33 R and D*

ACKNOWLEDGMENT

The author would like to thank Dr. N. S. Siddharthan and Dr. K.L. Krishna for their detailed comments on the paper.

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 and 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 and 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 and D efforts. Hence, it is important to capture the impact of R and 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 and D expenditures (measured by the difference between the total industry R and D and a firm's own stock of R and D), or through the use of patent data. Substantive literature has been published on measuring the R and 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). Given the nature of externality, firms need incentives to engage in R and D cooperation, either through taxes, subsidies or private incentives. Game theoretic models explain that if R and D spillovers are sufficiently high, R and D cooperation results in higher R and D investment and welfare gains for rival firms competing in the same industry (D'Aspremont and Jacquemin, 1988).

Empirically, little evidence has been found for horizontal spillovers (between rival firms engaged in the same industry) as oppose to vertical R and D spillovers (between upstream and downstream firms). Vertical and inter-industry R and D spillovers are found to have positive impact on productivity and investment as opposed to horizontal and intra-industry spillovers. (Vandwerf, 1992) discusses case studies of innovations initiated by customers and suppliers and suggests that vertical cooperation in R and D may increase the innovative success of participating firms. Case studies in the automotive industry also point out to the importance of vertical R and D collaborations between suppliers and OEMs (Womack *et al.,* 1990). However, more recent evidence in the context of Japanese automobile industry shows the presence of R and D collaborations among suppliers as well (Konno, 2007).

The present study attempts to analyze the impact of horizontal as well as vertical R and D spillovers within the same industry, from a supply chain perspective. Though firms may be suppliers to the same industry, they belong to different industries themselves; and different tiers of the supply chain. Hence there may be variation in access to knowledge within the same industry. Hence, intra-industry spillovers may have positive impact on the R and D intensity of a firm.

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 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 and D spillovers within the component subgroup, between the component subgroups and from the upstream firms consisting of the OEMs. 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.

LITERATURE REVIEW

The impact of R and D spillovers on R and D effort and productivity has been well researched. R and D spillover can be measured by using indicators of proximity or similarity between firms. Firms closer to each other benefit more from each others' work. Empirical work on R and D spillovers uses various ways to measure the proximity including use of patent data or industry data characterizing distribution of R and D expenditures across product categories (Jaffe, 1986). Alternatively, the sum of R and D expenditures of firms within an industry is also used as proxy for R and D information that is useful to its competitors. Some studies have also used R and D stock (accumulated knowledge of the firm) as a spillover variable to analyze the impact on the productivity of the firm. Two approaches to measure spillovers: firm's R and D effort (R and D expenditure), and firm's R and D stock (Harhoff, 2000; Chesbrough and Liang, 2008; Motohashi and Yuan, 2010). In the following section, impact of technology spillover on R and D effort and productivity is discussed using both the R and D expenditures (flow) and R and D stock perspective.

Spillovers Measured by Firm's R and D Intensity

Some of the pioneering works in the sphere of R and D spillovers are by Griliches (1979, 1994) and Cohen and Levinthal (1989). 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 and D expenditures. As a consequence of this assumption, high spillover rates have two effects. On one hand, they create the R and D disincentives; while on the other hand, the information externalities will induce the firm to step up its own R and 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 and D spending. R and 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 and D expenditures and vice versa.

The impact of R and 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 and D efforts by firms within the industry. Conversely, intra-industry spillovers are complementary to private R and D efforts for firms operating in industries with relatively large R and D expenditures, while they work as substitutes for private R and D in industries with a low R and D intensity.

Spillovers Measured by R and D Stock

R and D stock of a firm measures previously accumulated knowledge and also reflects the firm's absorptive capacity for new knowledge. Spillovers do not come costlessly to firms and firms may need to spend money and resources to absorb the new knowledge. In other words, firms own absorptive capacity is a function of industry spillovers. Also, the stock of knowledge that the firm possesses may be further determined by the stock of knowledge existing in the industry. Therefore, it is important to study the impact of R and D spillovers on the historical R and D stock of firms.

According to Harhoff (2000), "Firms may not be able to step up their R and D to capture a momentary increase in spillovers, but will depend on their historical R and D investments. Empirically, therefore, we should not necessarily expect productivity enhancing effects from spillovers per se, but firms with intensive prior R and D activities will be more likely to profit from spillovers". Harhoff studied the impact of R and D spillovers on R and D spending and productivity of firm for high technology and low technology intensity firms, using a panel data for German manufacturing firms. He estimated the R and D intensity (R and D spending/ R and D capital stock) as a function of the ratio of lagged R and D spending of firm and R and D capital stock of firm, external spillover[1] of R and D/R and D capital stock and sales/R and D capital stock. The study found that spillovers are stronger in high technology intensity firms with productivity enhancing effects. Consistent with absorptive capacity hypothesis, firms with higher R and D capital stock benefit more from external R and D.

More recently in the Indian context, a recent paper by Saxena (2011) found that technology stocks and spillovers have significantly affected the output of Indian manufacturing firms over the period 1994-2006.

[1] A proximity based measure of spillover was used, based on a firm's distribution of R and D expenditure across 34 product categories.

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

Apart from R and 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 and D effort. Inter-firm variations are found in R and D behavior of firms depending on size, technology intensity and ownership, across industries. A brief review of these studies is provided below.

Concentration

Farber (1981) found that industries characterized by both high buyer and seller concentration experienced higher R and D intensities. That is, a combination of oligopsony and oligopoly was most favourable for R and 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 and D collaboration and appropriate the benefits thereby.

Firm Size and Market Conduct

Advertisement and R and 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 over the period 1982-85, Siddharthan (1988) analyzed differences in R and D performed by small and large firms. He found that R and D intensity could fall with size, R and D and firm size 'U' shaped relationship. In another study that captures post-liberalisation period (Aggarwal, 2000), the author finds that R and 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 and D intensity. Siddharthan (1988), for example found that R and D and technology imports have a complementary relationship; adaptive R and D complements and not innovative R and D. In another study (Siddharthan, 1992), the author found that technology imports and FDI, both have a positive relationship with R and D effort. Aggarwal (2000), in her study of Indian manufacturing Industry analyzed the impact of technology imports on R and D efforts across two policy time frames: protection and deregulation. Her results showed that technology imports were only weakly related with the past in-house R and D efforts in the protective regime. Deregulation promoted complementarities between technology imports and R and D efforts significantly. She also found that post liberalization; local firms direct their R and 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 and D platform for their parents.

Outward Foreign Direct Investment: Pradhan and Singh (2009) undertake a quantitative analysis of the influence of OFDI activities on the in-house (domestic) R and D performance of Indian automotive firms during 1988–2008. 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 and D as they get proximity to innovation centers and innovative competitors in foreign countries. Other independent variables that are significantly affecting R and D activities of Indian automotive firms include age, size, disembodied technology, export intensity and foreign direct investment all of which have significant positive coefficients.

Industrial Clusters

The role of industrial clusters cannot be undermined for innovative activity within a firm. This is more so in the case of the automobile industry wherein the component firms are required to locate in close proximity to the assembler to facilitate Just in time (JIT). The growth of automotive clusters across regions in not only India, but in the US and other countries as well[2], corroborates this statement. Clusters aid innovative activity within a firm through external collaborations. Further, knowledge related to innovation is highly diffused within a cluster resulting in inter-firm differences.

A recent study (More and Jain, 2012) of Pune automotive cluster finds that firms within cluster tend to form collaborative organizations to promote and exploit various inter-firm linkages, and other institutions (such as university, research institutes and supportive institutions) tend to strengthen their information links. They find that the major sources of innovations are vertical spillovers coming from embodied technology acquisition, technology alliances, patent disclosure/scientific knowledge, assistance from global and local OEMs and technology transfer. These factors further enable the firms to position themselves in the global value chain. However, not much evidence is presented towards horizontal spillovers coming from within the cluster.

[2] 50% of North American automotive companies are based in Michigan. In India, the three main clusters are located in the North (Gurgaon), West (Pune) and South (Chennai).

Understanding R and D in the Context of the Automobile Industry

Since Liberalization, there has been a phenomenal growth in R and 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.

A comparison of the average R and D intensity across different segments of Indian automotive sector during 2000–2007 shows that commercial vehicle manufacturers have generally higher R and D intensity followed by two and three wheelers companies, automobile ancillary suppliers, and passenger cars and multi utility vehicles producers in that order. Further, the proportion of automotive firms with above 2 per cent R and D intensity has gone up from 4 per cent of the total number of firms in 2001 to 6 per cent in 2007[3].

Though the product development capabilities of the OEMs has increased as MNEs shift such activities to India, the R and 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 and D is still primarily oriented towards process development.

Much of the evidence in the automobile sector points out to the fact that the R and 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 and D spillovers may not be uniform across the automotive supply chain. Further, while the automobile industry is primarily characterized by

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[3] See Pradhan and Singh (2009) for more details.

vertical collaborations, underlining the importance of vertical R and D spillovers, recent studies have shown that there do exist horizontal R and D collaborations between suppliers, given the nature of automobile industry, where auto-component firms and car manufacturers must integrate their knowledge to manufacture a car. Konno (2007) found that Toyota has made aggressive efforts to coordinate the joint style advanced technology development projects that include two or more suppliers and horizontal cooperation between suppliers.

While the existing research on spillovers is very rich in terms of the nature and determinants of R and D spillovers, it has mostly emphasized the role of vertical spillovers as opposed to horizontal. The possibility that there can be considerable heterogeneity within an industry from a supply chain perspective has not been explored. Further, the difference in the flow and stock perspective has also not been analyzed to a great extent. The present study attempts to measure the R and D spillovers within the auto components Industry. 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 and a category `other' that manufactures miscellaneous automobile equipment. The study attempts to measure horizontal and vertical spillovers coming from the same industry, using the case of the Indian automobile industry.

OBJECTIVES

The objectives of the study are to determine the nature and magnitude of R and D spillovers across the automotive supply chain. To be specific, the study attempts to analyze the impact of horizontal spillovers coming from within the component industry; and vertical spillovers coming from the automotive assembler's R and D program, on the R and D effort of component firms. Horizontal spillovers are captured by classifying suppliers based on the component type. The study tries to capture the role of agglomeration economies on R and D spillovers by introducing a cluster variable, which identifies whether a firm is located within an automotive cluster. Finally, the study draws inferences regarding the implications of R and D spillovers on R and D collaborations within the supply chain of the automotive industry in India.

It differs from previous studies in the following way. Earlier studies have not found compelling evidence on the role played by horizontal spillovers and hence the focus has been mostly on vertical as opposed to horizontal spillovers. In this study, the impact of horizontal spillovers is captured in more detail by classifying within industry spillovers based on heterogeneity of suppliers. In the context of the automobile industry, spillovers are divided into those coming from within / outside the component group and those coming vertically from the automobile assemblers. Component firms are categorized into engine, electrical, suspension, transmission, tyres and a category `other' that manufactures miscellaneous automobile equipment.

Secondly, the present study analyzes spillovers using two specifications, from a flow and a stock perspective in order to analyze the impact of R and D spillovers on the absorptive capacity of firms.

METHODOLOGY

Two specifications are used to capture spillovers across the supply chain: one uses R and D expenditure as dependent variable; and the other specification uses R and D capital stock as the dependent variable. All variables were divided by sales (deflated values). R and D/Sales is defined as the R and D intensity for the particular firm.

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 and D expenditures of the firm from the total R and D expenditures of the component group it belongs to. The coefficient sign in this category is expected to be negative, that is, R and D spillovers within the group are expected to be a substitute for own firm R and 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 and D expenditures of a component group from the total R and 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 and D if the other component groups have also increased R and 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: An automobile product is made up of integral architecture with non-standard interfaces between numerous component parts. This requires close coordination between component makers and vehicle manufacturers in the design and development stage as almost all parts are custom made for the vehicle. Therefore substantial innovative activity takes place in such a vertical coordination process. Motohashi and Yuan (2010) find significant vertical spillovers in the Chinese automotive industry through technical support and employee training for improving the quality of parts. They cite the example

of Toyota which dispatched more than 150 engineers to its local partner to introduce Toyota Production System.

Spillovers from automotive manufacturers are measured by the R and 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 and D Intensity

The following relationship is estimated:

$R_{it}/S_{it} = \alpha_{it} + \beta_{1t} R_{-it}/S_{it} + \beta_{2t} R_{jt}/S_{it} + \beta_{2t} R_{oem}/S_{it} + \beta_{4t} Dtech/S_{it} + \beta_{5t} \delta_t + \beta_{6t} (\delta_t * R_{it-1}/S_{it-1}) + \beta_{7t} (\delta_t * R_{-it}/S_{it}) + \beta_{8t} (\delta_t * R_{jt}/S_{it}) + \sum \beta_{it} X_{it}$

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}/S_{it} is the R and D intensity measured as R and D expenditure divided by sales.
- Horizontal spillover from within the group is measured by R_{-it}/S_{it} which consists of R and 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 and 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 and 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 and 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 and 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.
- δ_t is a time invariant dummy variable which takes the value of 1 if the firm belonged to an auto cluster; that is if it was located in either Gurgaon/Faridabad, Pune or Chennai (Ford/Hyundai auto cluster), and 0 otherwise.
- Two interaction terms (between the dummy and spillover variables) are introduced to capture the impact of spillovers of firms located within an auto cluster and outside it.
- X_{it} represents control variables consisting of number of employees and market share.

Model 2: Spillovers from R and 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 and D expenditures for the past five years (1996-2001) after deflating them by the appropriate price index. In calculating an R and D stock, evidence supports the use of the Perpetual Inventory Method (PIM). The gross stock of R and D would be a measure of the cumulative value of past investment still in existence and the rate of depreciation is taken as 15% as a starting point, though other studies[4] have used different rates of depreciation.

Equation (1) is now estimated with the dependent variable being the R and D stock intensity measured as R and D stock divided by sales.

[4] Nadiri and Prucha (1993), Bernstein and Nadiri (1989).

Endogeneity of Spillover Variables

In Panel data models usually specified as $Y_{it}= X_{it}\beta +(\alpha_i +u_{it})$, where α_i (individual specific time invariant effect) and u_{it} (error term) are not observed, it is usually assumed that u_{it} is is serially uncorrelated and α_i is also not correlated with the X_i's. In such a case, α_i gets included with the error term u_{it}. However in case α_i is correlated with the X_i's, this gives rise to omitted variable problem. For example, there may be unobserved firm specific characteristics that may be related to the spillover variables. If these are not specified, then the results will be biased.

In other words, there are two parts to the beta estimator of the variable: one that is specific to the individual observation and does not vary across time (time invariant) and one which varies over time between individuals. These two parts are called "between estimator" and "within estimator". In the random effects model, the effect of both these is assumed to be equal, whereas, however if the effect of both is different, then the results are biased giving rise to the endogeneity problem. The fixed effects approach resolves this problem by eliminating the time invariant effect from the model by time-demeaning the data and obtaining the within-effects estimator.

However, this does not solve the problem of endogeniety. One approach is to retrieve the time invariant effects by regressing the means of the within residuals on these variables. Hausman and Taylor (1981) provide an efficient instrumental variable estimation of the model when some of the explanatory variables and time invariant variables are correlated to the individual level random effects. This approach involves two-stage instrumental variable estimation, where the instruments are selected from within the model itself. Valid instruments are given by the other time invariant and time varying variables in the equation.

An alternate approach is that of Mundlak (1978) where the author studied the error component model with individual effects and with possible correlation of these individual effects with the explanatory variables. Specified this way, the within effect estimator obtained is the same as the FE approach. Mundlak formulation simply adds one additional term in the model for each time-varying covariate, accounting for the between-individual effect: that is, the individual mean.

In the present paper, it is assumed that the spillover variables may be endogenous. For example, within group and outside group spillovers may be firm-specific and related to variables such as technology acquisition, age and whether they are suppliers to OEMs in the two-wheeler or four wheeler categories. The paper estimates the Hausman Taylor approach and presents the results in section VI. The Mundlak formulation is also estimated and results are presented in the appendix (Table A.3), as the coefficients of the mean values (between estimator) do not appear significant.

DATA AND DESCRIPTION OF VARIABLES

Data is obtained from CMIE's Prowess database consisting of more than 500 firms in the automotive sector, which was classified into six component categories: engine, electrical, suspension, transmission, tyres and others (equipment). Table A.1 in the appendix gives a detailed break-up of the type of firms classified under each component group. After accounting for firms with positive sales in any year, 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: Force Motors and Mahindra and Mahindra, which were grouped along with the commercial vehicle category. Tables A.2 and A.2a in the appendix show the number of firms in each category of component and OEM group.

Table 1 provides the descriptive statistics for variables used in the study. Average R and D expenditure and R and D stock during 2002-

2011 is highest in the engine category, followed by Suspension and Tyres. Average number of employees is highest in the tyres category followed by electrical and engine categories. Average royalty payments are highest in the engine category followed by electrical and suspension.

R and D: R and D expenditure broadly comprises expenditure on equipment, plants and machinery and salaries of R and 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 and 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 and D expenditures. Tables 2 and 3 show the R and D intensities for the auto component categories and the original equipment manufacturers (OEMs). R and D intensities show an increasing trend for the OEMs but a declining trend for the component categories during 2002-2012.

In the present study, the R and D expenditures are deflated by the WPI for capital equipment (machine and machine tools) for the respective years before calculating the stock. The base year is 2004-05. The data was obtained from the office of Economic Advisor[5], Ministry of Commerce and Industry, Government of India. Figures 1-4 show the R and D expenditure and stock for auto component suppliers and OEMs. The trend is highest for engine followed by suspension and tyres.

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

[5] http://eaindustry.nic.in/wpi_data_display/display_data.asp (accessed as on October 2013)

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.

Age: Data on age of firms was imputed from the year of incorporation available from Prowess database.

Sales: The annual sales was deflated by CPI (IW) to arrive at sales measured at constant 2004-05=100 prices. The CPI (IW) was obtained from RBI's database.

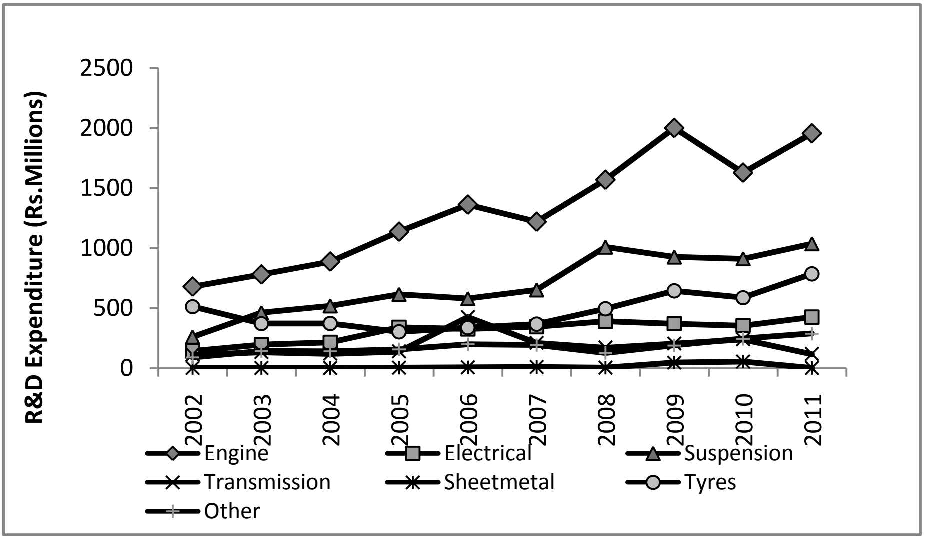
Technology Intensity: Expenditure on royalties and license fees was used as a measure of disembodied technology imports. This was deflated by the WPI series for capital equipment for respective years.

Market Share /Concentration: Market share of each firm within its component group was calculated. Herfindahl index was also 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. In the estimation, H-index is insignificant and hence dropped.

Industry Cluster: The location of firms and their plants were identified as to whether they belonged to an automobile cluster or not. The addresses and plant locations were found through the Prowess database and also through individual company websites.

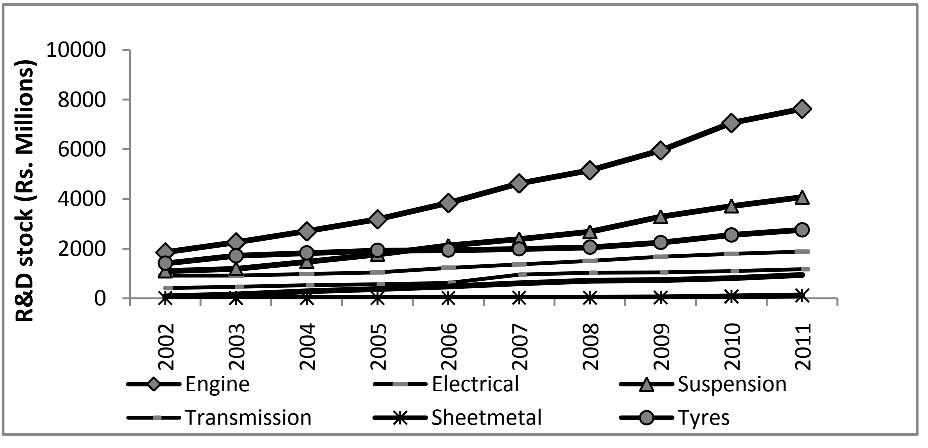
Interaction Term: Two interaction terms were introduced between the industry cluster and the spillover variables to understand the magnitude of within and outside group spillovers if a firm was located within an automobile cluster.

Figure 1: R and D Expenses of Auto Component Groups



Source: Prowess database, CMIE.

Figure 2: R and D Stock of Autocomponent Groups



Source: Prowess database, CMIE.

Table 1: Descriptive Statistics

Categories	R and D exp Rs. Millions	R and D stock Rs. Millions	H-Index	Royalty payments-Rs. Millions	R and D_ Spillover within groups Rs.Millions	R and D_ Spillover outside group Rs.Millions	Employees	Sales Rs. millions
Engine								
Mean	1322	4424	0.07	27	1287	1868	1530	163987
Std.Dev	467	2008	0.01	18	458	528	314	63840
Median	1291	4233	0.06	20	1250	1832	1775	169699
Min	680	1852	0.06	11	660	1121	1093	69998
Max	2001	7628	0.09	66	1952	2662	1897	251741
Electrical								
Mean	311	1335	0.18	12	278	2879	1981	68865
Std.Dev	93	370	0.01	4	84	905	421	33324
Median	344	1304	0.17	10	309	2786	2070	62870
Min	143	917	0.16	6	130	1658	1481	29851
Max	426	1884	0.19	20	390	4192	2807	123971
Suspension								
Mean	698	2384	0.07	14	671	2492	1186	88280
Std.Dev	261	1048	0.01	5	251	746	330	34666
Median	634	2257	0.06	13	608	2507	1417	93555
Min	260	1101	0.06	8	249	1541	730	38784
Max	1038	4078	0.09	22	1005	3580	1619	133262
Transmission								
Mean	189	793	0.07	2	177	3002	817	50882
Std.Dev	95	293	0.00	1	89	968	162	18139
Median	156	795	0.07	2	146	2804	960	53089
Min	113	419	0.06	1	105	1688	599	25157
Max	427	1172	0.08	3	399	4499	980	76358
Sheetmetal								
Mean	14	32	0.12	0.002	11	3176	857	32017
Std.Dev	20	35	0.03	0.005	17	977	356	11686
Median	5	16	0.12	0.000	4	3114	1087	34517
Min	2	9	0.10	0.000	2	1799	318	13024
Max	55	115	0.17	0.016	48	4615	1313	43862
Tyres								
Mean	478	2040	0.14	7	445	2712	3071	180371
Std.Dev	157	393	0.01	2	149	881	447	54136
Median	433	1962	0.14	7	404	2770	2911	181345
Min	303	1410	0.13	4	279	1288	2549	105891
Max	786	2755	0.15	10	743	3832	4197	270229
Other								
Mean	178	518	0.11	7	160	3012	711	24783
Std.Dev	59	289	0.02	4	56	944	239	9843
Median	174	544	0.10	7	152	2926	768	25838
Min	91	80	0.08	2	83	1710	388	9947
Max	289	938	0.15	15	271	4329	1068	37626
No. of firms	88	88	119	119	88	88	119	119

The data includes only firms which had positive R and D in any year during 2002-2012.
Source: Prowess database, CMIE.

Figure 3: R and D Expenses of Auto OEMs

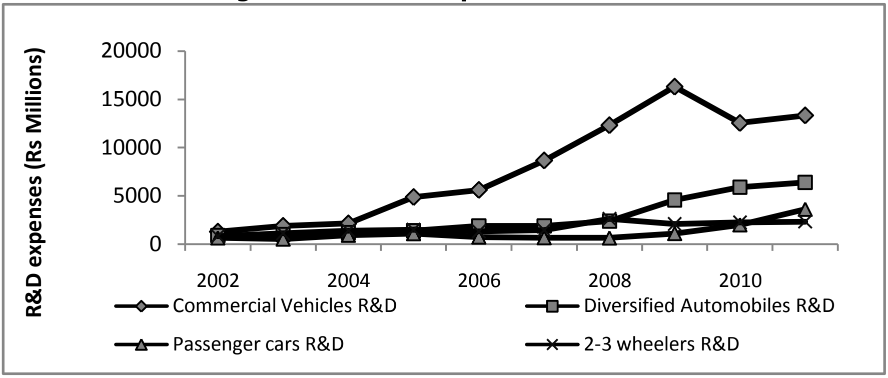
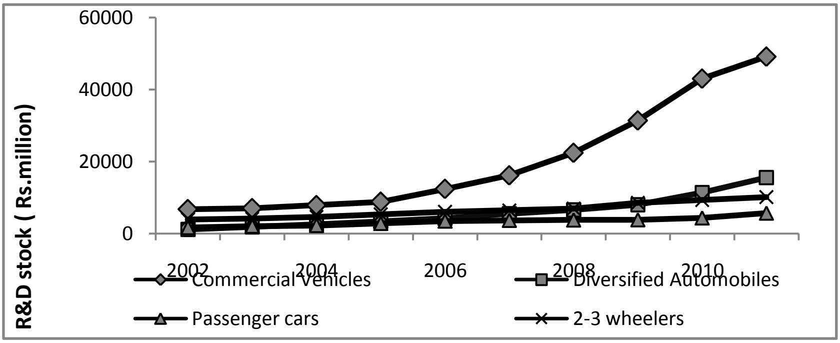


Figure 4: R and D Stock of Auto OEMs



Source: Prowess Database, CMIE

Table 2: R and D Intensity in the Indian Auto Component Industry in %

Year	Engine	Electrical	Suspension	Transmission	Sheetmetal	Tyres	Other
2002	1.0	0.5	0.7	0.4	0.0	0.5	0.9
2003	0.9	0.6	1.0	0.5	0.0	0.3	1.2
2004	0.8	0.6	0.9	0.4	0.0	0.3	0.9
2005	0.9	0.8	0.9	0.3	0.0	0.2	0.8
2006	0.9	0.6	0.7	0.9	0.0	0.2	0.8
2007	0.7	0.5	0.6	0.3	0.0	0.2	0.6
2008	0.7	0.4	0.8	0.3	0.0	0.2	0.5
2009	0.9	0.4	0.8	0.4	0.1	0.3	0.6
2010	0.7	0.3	0.8	0.4	0.1	0.2	0.7
2011	0.8	0.3	0.8	0.2	0.0	0.3	0.8

Source: Prowess database, CMIE.

Table 3: R and D Intensity in the Indian Automotive OEMs in %

Year	Rdint_CV	Rdint_DV	Rdint_PC	Rdint_TW
2002	1.2	1.9	0.4	1.0
2003	1.4	1.8	0.3	1.1
2004	1.1	1.7	0.4	1.0
2005	2.0	1.6	0.4	0.9
2006	1.9	1.9	0.3	0.7
2007	2.2	1.6	0.2	0.7
2008	2.9	1.9	0.2	1.0
2009	4.5	3.4	0.3	0.8
2010	2.6	3.3	0.4	0.8
2011	1.9	3.1	0.7	0.6

Source: Prowess database, CMIE.

CV and DV refers to Commercial vehicles and Diversified vehicles respectively; PC refers to Passenger Car segment; TW refers to Two Wheeler segment.

RESULTS AND DISCUSSION

Table 4 shows the correlation between the variables used in model 1. There is high correlation between outside group spillover variable and R and D intensities of OEMs. There is also a high correlation between R and D of commercial vehicles and two and three wheelers (0.95).

Table 4: Correlation among Variables Used in Model 1

Variables	**R and D intensity**	**Within group spillover intensity**	**Outside group spillover intensity**	**Technology intensity**	**Firm market share**	**Employees**	**R and D intensity_ CV and DV**	**R and D intensity_ PC**	**R and D intensity_ two-three wheelers**	**Industry Cluster (dummy)**
R and D intensity	1	0.053	**0.42 *****	**0.078 *****	**-0.06 ****	0.012	**0.43*****	**0.29*****	**0.34*****	0.03
Within group spillover intensity		1	**0.55 *****	-0.048	**-0.17 *****	**-0.15*****	**0.63*****	**0.60*****	**0.72*****	0.04
Outside group spillover intensity			1	**-0.10 *****	**-0.19 *****	**-0.17*****	**0.94*****	**0.92*****	**0.96*****	**-0.07****
Technology intensity				1	0.002	0.0075	**-0.086*****	**-0.11*****	**-0.099*****	**0.07****
Firm market share					1	**0.86*****	**-0.16*****	**-0.22*****	**-0.21*****	**-0.07*****
Employees						1	**-0.14*****	**-0.19*****	**-0.19*****	-0.007
R and D intensity_ CV and DV							1	**0.89*****	**0.95*****	-0.053
R and D intensity PC								1	**0.92*****	**-0.072****
R and D intensity two-three wheelers									1	-0.045
Industry Cluster (dummy)										1

Source: Prowess database;

***, ** represent significance at 1% (p<0.001) and 5% (p<0.005) level respectively.

CV and DV refers to Commercial vehicles and Diversified vehicles respectively. PC refers to Passenger Car segment

Table 5 shows the Hausman statistics and the model estimations from fixed versus random effects regression. Hausman test was significant, suggesting a fixed effects model for estimation.

Table 5: Fixed Effects (FE) vs. Random Effects (RE) Estimation for Model 1

Variables	FE specification	RE Specification
Within group spillover intensity	0.00045 (0.0019)	-0.00401 (0.0012)
Outside group spillover intensity	0.00262 (0.0003)	0.0026 (0.00026)
Technology intensity	0.073 (0.075)	0.10 (0.062)
Employees	2.93e-07 (3.21e-07)	3.38e-07 (1.44e-02)
Firm market share	-0.0542 (0.022)	-3.15e-02 (1.44e-02)
R and D intensity_Commercial and Diversified vehicles	0.000167 (4.54e-05)	0.0001415 (3.75e-05)
Age	-0.00049 (0.00013)	-0.000491 (0.00012)
R and D intensity_Passenger vehicles	-0.0031 (0.00033)	-0.003 (0.00028)
R and D intensity_two-three wheelers	-0.00152 (0.0004)	-0.0013 (0.0004)
Industry_cluster		0.0039 (0.002)
within spillover* industry_cluster	-0.0014 (0.002)	0.0037 (0.0013)
outside_spillover* industry_cluster	-0.0012 (0.0002)	-0.00121 (0.0001)
chi2(8) = (b-B)'[(V_b-V_B)^(-1)](b-B) =27.88 **Prob>chi2 = 0.0010**		

Dependent variable is R and D Intensity; Figures in parentheses are standard errors.

Tables 6 and 7 show the results for fixed effects regression estimates for models 1 and 2 respectively. The dependent variable in model 1 is R and D expenditure divided by sales while for model 2, the dependent variable is R and D stock divided by sales. Column (1) shows results from fixed effects estimation and Column (2) shows results from Hausman Talyor Random effects estimation. The spillover variables are assumed to be endogenous and related to firm specific individual effects. They are also correlated with some of the explanatory variables like R and D intensities of the OEMs. Hence these variables can be used as instruments for the endogenous variables. The results of Hausman Taylor and the Fixed effects model are very similar with similar coefficient signs and standard errors. The Hausman Taylor model estimates in addition, the industry cluster variable, which is positive and significant for model 1.

Table 6: Results from Fixed Effects Estimation for Model 1

Variables	Fixed Effects	Hausman-Taylor Random Effects
Within group spillover intensity #	0.00045 (0.0019)	-0.002 (0.0015)
Ouside group spillover intensity #	0.00262*** (0.0003)	0.0026 (0.0002)
Technology intensity #	0.073 (0.075)	0.08 (0.07)
Employees	2.93e-07 (3.21e-07)	3.4e-07 (2.27e-07)
Firm market share	-0.0542*** (0.022)	-0.035 (0.017)
R and D intensity_Commercial and Diversified vehicles	0.000167*** (4.54e-05)	0.00014 (0.00004)
Age	-0.00049*** (0.00013)	-0.00047 (0.00012)
R and D intensity_Passenger vehicles	-0.0031*** (0.00033)	-0.00313 (0.0003)
R and D intensity_two-three wheelers	-0.00152*** (0.0004)	-0.0015 (0.0004)
Industry_cluster $		0.0053** (0.0025)
Within_spillover* industry_cluster	-0.0014 (0.002)	0.0015 (0.0016)
Outside_spillover* industry_cluster	-0.0012*** (0.0002)	-0.0011 (0.00015)
_cons	0.021*** (0.0003)	0.015 (0.0034)
R-Square: Within	0.3884	
Between	0.5811	
Overall	0.3002	

R and D Intensity is defined as ratio of R and D Expenses and sales
*** at 1%; ** 5% and * 10% level of significance.
Figures in parantheses are robust standard errors. # refers to Time varying endogenous variables; $ refers to time invariant variable and the rest are time varying exogenous variables in the Hausman Taylor model.

Table 7: Results from Fixed Effects Estimation for Model 2

Variables	Fixed Effects	Hausman-Taylor Random Effects
Within group spillover intensity #	-0.0015 (0.0017)	-0.0018 (0.0013)
Outside group spillover intensity #	0.0010*** (0.0004)	0.0010 (0.0003)
Technology intensity #	-0.11 (0.17)	-0.081 (0.16)
Employees	-0.0000 (7.08e-07)	5.35e-07 (6.28e-07)
Firm market share	-0.39*** (0.0003)	-0.32*** (0.045)
R and D intensity_Commercial and Diversified vehicles	-0.00015 (0.05)	-0.0001 (0.0001)
Age	0.0017*** (0.0001)	0.0015*** (0.0002)
R and D intensity_Passenger vehicles	-0.0013* (0.0008)	-0.0013* (0.0007)
R and D intensity_two-three wheelers	-0.0010 (0.0008)	-0.001 (0.0008)
Industry_cluster $		-0.006 (0.011)
Within spillover* industry_cluster	-0.0003 (0.0019)	-0.00008 (0.0014)
Outside_spillover* industry_cluster	0.0012*** (0.0003)	0.0011*** (0.0002)
_cons	0.004*** (0.006)	
R-Square: Within	0.7608	
Between	0.1639	
Overall	0.2549	

R and D Intensity is defined as ratio of R and D stock and sales

*** at 1%; ** 5% and * 10% level of significance

Figures in parantheses are robust standard errors. # refers to Time varying endogenous variables; $ refers to time invariant variable and the rest are time varying exogenous variables in the Hausman Taylor model.

Horizontal Spillovers: R and D within the component group acts as substitutes to own firm R and D. R and D expenses outside the firm's component group are complementary to firm's own R and D expenditures.

ii. Outside group spillover coefficient is positive and significant in both models, but the magnitude is higher for model 1. R and D intensity of firms outside the component group have a positive effect on a firm's own R and D intensity. In terms of magnitude, a 1% increase in R and D intensity of firms outside the component group, results in ~0.3% increase in own R and D intensity as measured by R and D expenditure and 0.1% increase in R and D intensity as measured by R and D stock. It also suggests that outside group spillovers are associated with a higher knowledge stock or absorptive capacity of firms and this effect increases if the firm is located inside a cluster as suggested by the coefficient of the interaction term.

    The interaction term on between outside group spillover and dummy variable is negative in model 1 but positive in case of model 2. In both cases, the coefficient is significant. The impact of outside group spillover measured by current R and D expenditure is substitutive for firms located inside a cluster. However, the impact is positive as measured by R and D stock, implying that outside group spillovers have positive impact on firms' absorptive capacity if they are located inside a cluster.

iii. Within group spillover coefficient is positive in model1 and negative in case of model 2, but is not significant in both models. R and D intensity of firms within the group does not have any effect on firms' own R and D intensity.

- **Vertical Spillovers**

The coefficient on R and D intensity of passenger car vehicles is negative and significant in both models, but the magnitude is higher in model 1. Similar result is obtained for two/three wheelers as well, but it is not significant for model 2. These results suggest that R and D spending in passenger car and two/three wheeler industry has a substitutive effect on firm's own R and D spending, implying the presence of an externality. It might suggest that R and D expenditure on process changes on the assembly line and incremental innovations get transferred to the component manufacturers in the form of cost savings in processes, resulting in lower expenditure on equipment and machinery.

However, this does not explain the degree of collaboration in product development between the OEMs and suppliers. Unlike the case of the Japanese industry, where there is vertical R and D collaboration between the OEM and supplier when they jointly file for patents, no such evidence is yet available in the case of India.

The coefficient on R and D intensity of commercial vehicles is positive and significant in case of model 1 but the magnitude is very small (a 1% increase in R and D intensity of commercial vehicle manufacturers results in ~ 0.02% increase in R and D intensity of the firm. In general, the R and D expenditures are highest in case of commercial vehicle manufacturers because of higher wear and tear of machinery as well as products. There might be a higher degree of collaboration between the suppliers and the manufacturers at the product development stage itself.

- **Control Variables**
  1. Market share of firms is negative and significant in both the models, the magnitude being higher for model 2. A 1% increase in market share of firm results in 5% decrease in R and D intensity in case of model 1 and 39% decrease in R and D intensity in case of model 2. The result suggests that higher market share comes at the expense of innovative activity and firms which tend to put more effort on increasing their market share tend to do so by focusing on the lower end of the value chain which does not require high R and D effort.

ii. Age has a negative effect on R and D intensity of firms in case of model 1 but positive effect in model 2. Both the results are significant. This suggests that current R and D spending is decreases with age of firm; however, the R and D stock or the absorptive capacity of the firm increases with the firm's age.
iii. The impact of industry cluster dummy variable is positive and significant in model 1, negative, but not significant in model 2. The result suggests that firms which are located within an automotive cluster have higher R and D intensity.
iv. Technology intensity is positive in model 1 but negative in model 2, both of which are not significant. The effect of number of employees is negligible and the coefficient value is not significant in both models.

CONCLUSION

An important finding of the study is with regard to the effect of R and D spillovers horizontally and vertically across the supply chain of an industry. In contrast to previous studies which did not find positive impact of spillovers within an industry, the results of present study suggest otherwise because it attempts to model the heterogeneity of firms within the same industry. The results show that within the industry spillovers coming from outside the group of homogenous firms have a positive and significant impact on both current R and D expenditures as well as R and D stock of firms, which is indicative of a firm's absorptive capacity for new knowledge. The study further finds that the impact of such spillovers on the absorptive capacity of firms is higher if they are located within an automotive cluster. This is an important finding which underlines the importance of agglomeration economies in a cluster.

The result on market share suggests that firms that tend to concentrate efforts towards increasing market share tend to spend lesser effort on R and D activity which is contrary to previous studies that have shown that higher market share helps R and D effort; further, a more concentrated industry structure increases R and D intensity because of better appropriability regime. The results of the present study do not support this hypothesis.

In the context of the automobile industry, the present of positive spillover effect between component groups suggests that firms compete and collaborate at the same time within a supply chain. This is also in line with the nature of the product, which has an integral architecture, requiring collaboration across suppliers.

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APPENDIX

Table A.1: Component Groups Classification

Engine	Electrical	Suspension	Transmission	Other
Automobile engine parts	Electric horns	Air brakes	Gears including crown wheels	Other auto lights
Automobile engine parts, nec	Starter motors	Oil seals	Propeller shafts	Other autopanel instruments/parts
Engine Airconditioning machines/systems	Rotor pumps	Auto hydraulic pneumatic equipment	Wheels for automobiles	Auto headlights
valves	Electrical automobile parts	Axle housing/ front axle assembly	Wheels/wheel rims	Auto bulbs
Pistonrings, Pistons	Separators	Bimetal bearings	Axle shafts	Auto castings
Fasteners	Wiring harness and parts	Brake assembly	Clutch assembly	Automobile equipment
Radiators	Lead-acid accumulators	Brake linings	Clutch facings	Automobile locks
Carburettors, Gaskets	Storage batteries	Suspension and braking parts	Clutch plates/discs	Automotive filters
Crankshafts	Software services	Thickwall, thinwall bearings	Drive transmission and steering parts	Wiring harness

(Contd … Table A.1)

Engine	Electrical	Suspension	Transmiss-ion	Other
Exhaust systems and components		Auto seating systems		
Filter elements,inserts	**Sheetmetal**	Steering gears	**Tyres**	
Flywheel magnetos	Auto plastic moulded components	Steering linkages	Tyre treads	
Turbo jet	Auto sheetmetals parts	Shock absorbers	Tyre tubes	
Leaf springs(Automotive)	Automobile bodies	Auto dashboard instruments	Tyres	
Flywheel ring gears	Bus body	Hydraulic pumps	Tyres and tubes	
Fuel injection equipment			Retreaded and other tyres	
Fuel injection equipment spares			Retreaded tyres	
Valve guides/pushrods			Motor tyres	
Cylinder liners			Cycle tyres	
Water pump assembly			Pressure gauges	
Timing chains				

Source: Prowess database.

Table A.2: Sample Size of Various Component Groups

Component Group	No. of Firms
Engine	73
Electrical	20
Suspension	40
Transmission	42
Sheetmetal	20
Tyres	29
Other	20

Source: Prowess database

Table A.2a: Sample size of Automobile Manufacturers

OEM Group	No. of Firms
Commercial Vehicles	9
Diversified Automobiles	2
Passenger Cars	9

Source: Prowess database

Table A.3: Mundlak Formulation: Model 1

R and D intensity	Col (1) Coefficients	Col (2) Coefficients for Mean Values
Within group spillover intensity	0.0005 (0.006)	-0.0021 (0.007)
Between group spillover intensity	0.003 * (0.002)	-0.00053 (0.003)
Technology intensity	0.067 (0.087)	0.085 (0.123)
Age	-0.0005 ** (0.0002)	(omitted)
Firm market share	-0.056 (0.037)	0.0402 (0.052)
Employees	2.60E-07 (2.17E-07)	-6.59E-08 (4.00E-07)
R and D intensity_Commercial and Diversified vehicles	0.00015 (0.0001)	0.0003 (0.0002)
R and D intensity_Passenger vehicles	-0.0031 *** (0.001)	-0.0036 (0.003)
R and D intensity_two-three wheelers	-0.0014** (0.0007)	0.00042 (0.0056)
Industry_cluster (dummy variable)	0.0031 * (0.002)	
Within spillover* industry_cluster	-0.00146 (0.0065)	0.0037 (0.0072)
outside_spillover* industry_cluster	-0.0012 (0.0013)	0.000185 (0.0014)
_cons	0.017 *** (0.005)	
RSq.:Within=0.39 Between= 0.73 Overall: 0.42		

Figures in parantheses are standard errors
*** at 1%; ** 5% and * 10% level of significance

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