R&D Spillovers and R&D Intensity: A Study of Electronic Goods Sector in India

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Abstract

This paper attempts to analyze the determinants of inter-firm differences in R&D intensity at the five digit level of industries belonging to the Electronics Goods Sector in India. Empirical literature mostly focused on the role of technology imports, firm size and age in determining R&D intensity. The extant literature following Cohen and Levinthal (1989) points to the possibility of learning through R&D Spillovers for every firm belonging to a specific industry.

Using Panel data estimation for the period 2002-2014, this paper finds that firms benefitting from R&D Spillovers in their line of business are spending less on in-house R&D activity. The results, however, suggest complementarity between in-house R&D efforts and R&D Spillovers for select industries within this sector. Age of the firm, representing the learning by doing proposition, turned out with a positive and significant co-efficient. When R&D spillover is considered interacting with the age of the firm, we find that older firms that benefit from R&D Spillover appear to be less engaged in in-house R&D efforts. Further, small sized firms appear to be more R&D intensive than their larger counterparts, whereas vertically integrated firms are spending less on in-house R&D efforts. The paper highlights the possibilities of benefits appropriated by large and older firms from the available pool of R&D Spillovers. Small as well as young firms continue to rely on in-house R&D for their survival and growth. Also, the results clearly point out inter-industry differences, based on product lines, in technological efforts in the electronic goods sector in India.

***JEL classification*: L1, L63**

1. Introduction

With the increased demand world over for more and more cross boundary trade facilitated by the new age technological revolution, firms whether a newly born start up or an existing giant incumbent are facing ‘cut-throat’ competition for survival, maintaining market share and profit margin, and market value in the eyes of the shareholders. In fact, in today’s world (domestic) firms face competition not only from within the domestic industry, but rather more aggressive competition is felt from across the national boundaries with flooding of similar or qualitatively differentiated (at times superior) products that are constantly threatening the domestic firms to manage their existence in the business. In addition, the potential danger of hostile takeovers also looming large at them; and in many cases the domestic firms have to save themselves by merging with another domestic player or with a foreign venture to sustain themselves.

It is in this backdrop that businesses and academics started arguing that it is a mere necessity to continuously upgrade/ improve the products and processes to remain in the business and look for opportunities to offer improved variety of goods and services. Hence, the need is felt to look somewhat deeper into the firm level R&D activities that the modern corporate firms are bound to undertake to maintain (if not improve) their basic objectives such as increased sales turnover and profitability.

The famous Schumpeterian hypothesis and subsequent theoretical research emphasized on the intensity and direction of R&D efforts at the firm level under different forms of market structure; see, Schumpeter (1942), Arrow (1962), and Dasgupta and Stiglitz (1980).[1] However, the theoretical arguments were set for empirical validity beginning from mid-1960s and it has been a world-wide journey with inconclusive empirical results whereby there is no certain consensus on even the empirical validity of the famous Schumpeterian hypothesis. Thus, the objective of this paper is to examine the determinants of firm level R&D intensity where we focus on the role played by R&D spillovers along with other traditional firm characteristics such as firm size, age of the firm and technology imports in the context of electronic firms operating in India. Justification behind our selection of the electronics industry is highlighted in Section 3. We confine ourselves to the data period 2002-2014 because (i) till 2012, *GoI* did not have any national policy framework explicitly for the electronics sector; (ii) the Indian electronics industry took off after the mid-1990s; and (iii) the domestic supply for Indian electronic products were significantly small and had a negligible share in the world market. It is only in the late 1990s that the Indian electronics market started flourishing and the supply bottlenecks got gradually eased with foreign firms entering into the market along with domestic firms reallocating their resources towards R&D activities.

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[1] Schumpeter (1942) argues that the “… actual efficiency of the capitalist engine of production in the era of the largest-scale units has been much greater than in the preceding era of small or medium sized ones” (p. 189). Schumpeter (*ibid.*; p. 81) went on saying that “… the modern standard of life of the masses evolved during the period of relatively unfettered big business.” In effect, the *sine qua non* that exalts competitiveness in terms of cost advantage and learning is the *size* of firms amongst other significant attributes such as age and along with it knowledge accumulation.

The rest of the paper is organized as follows. Section 2 presents a brief review of literature on the relation between R&D efforts and R&D Spillovers and other firm characteristics. Section 3 presents an Overview of the Electronics Goods Sector in India. Section 4 describes the Data, Variables and their measurement. Section 5 presents the Descriptive statistics. Section 6 illustrates the Estimation methodology and presents the Empirical analysis. Section 7 concludes the paper.

2. A Brief Literature Review

Spillovers and R&D Efforts

A growing body of literature has attempted to examine the impact of R&D spillovers on in-house R&D efforts. Microeconomic analyses emphasize that spillovers may influence the incentives to engage in innovative activities [Geroski *et al*. (1993)].[2] Arrow (1962) considered the *positive externalities* associated with private investment in industrial R&D; see, Arrow (1962) for details. It was argued that that *involuntary* transmission of knowledge to competitors may weaken the firm's incentive to invest in R&D activities. At the same time, restricting "the use of the information by the original possessor" *only* "may not be of much use to the owner of the information either, since he may not be able to exploit it as effectively as others"; Arrow (*ibid.*, p.615). However, it is not denied that possible spillovers of technological knowledge are inevitable; Levin (1988). In a simple static model, Spence (1984) found that an increase in spillovers reduces the incentive to invest in R&D. At the same time it also reduces the R&D required to achieve a given level of cost reduction for agents (the *fringe competitors*) absorbing the benefits of such spillovers. In the context of the Indian Electronic Industry both the young and the old firms within the industry may require new knowledge's or ideas from beyond its boundaries to remain competitive. As a consequence the incumbents in this industry may rely more extensively on externalities such as spillovers that may be from R&D expenditure of other firms within the industry or from cooperative modes such as joint ventures or mutual exchanges of know-how. Therefore, we may anticipate in-house R&D efforts to be influenced by the existence of R&D spillovers in the form of ideas generated from R&D activities undertaken by other incumbents. In the context of economic policy formulation it is important to understand the effects of these R&D spillovers on the firm's own R&D investment decision (Harhoff, 2000).

While spillovers may influence R&D efforts, it is imperative to undertake one's own R&D activity to develop "absorptive capacity" so as to assimilate new ideas or research from the outside. That is, any strategic move to innovate by taking advantages from the outside precedes some investment in the form of firm's own R&D. The theory of "absorptive capacity" suggests an interaction between the firm's own knowledge stock and the available spillover pool in the R&D spending regression. While the availability of outside information and ideas through

[2] Spillovers of technological activity that affects profitability also influences the incentive to undertake R&D. Spence (1984) presents the theoretical model of R&D competition with spillovers and theoretically illustrated that the firm's R&D intensity will be a decreasing function of the extent of spillovers, computed as the share of R&D expenditures that effectively reaches all competitors.

spillovers has incentive effects, the effective exploitation of that information depends on the firm's own prior R&D investments. Thus firms with relatively more intensive prior R&D activities will be more likely to adapt and exploit incoming R&D spillovers. Even in a competitive setting with few dominant firms and a set of fringes, if the fringes are dependent and have a subordinate role in relation to other dominant firms, it may not be able to initiate any new product design without adequate own R&D facilities. Most of the small firms in capital intensive industry fall into this category. These firms usually supply components, tools and equipments to the finished product producing dominant firms. The decision to undertake R&D activity is principally guided by the incentive to undertake such efforts. While the fringes are likely to absorb and assimilate learning and new knowledge from its dominant counterpart, the dominant firms needs to accommodate fringe innovation rather than deter it for the industry to grow as a whole. For instance, the American Machine Tool Industry that consists of a large number of relatively small firms, generates its "shelf of design ideas" from the customers of the machine tool industry [Brown (1957)]. These customers, who are the large firms, are in effect the buyers of the products of dependent firms. In spite of their weak market position, the dependent firm may enjoy good profits by increasing the demand for their machine tools, by customising the new design to the buyer's need, thereby rendering the old designs obsolete. This too requires a priori some investment in R&D efforts by small firms on one hand and knowledge flow on the other.

Spillovers from rivals might stimulate the firm's present R&D activities or attenuate them.[3] In the former, outside spillovers are *complementary* to the own firm's R&D, whereas the latter illustrates the *substitutability* between spillovers and past R&D expenditures.[4] Also, the less research intensive the firm is, the more it may be inclined towards absorbing incoming spillovers. This may be because the firm may be away from the "frontier of technology" and have to learn from other firms (Jirjahn, 2007). This *positive* interaction effect is theoretically hypothesized by Cohen *et al*. (1989). Firm level R&D enhances the absorptive capacity of the

[3] Spillovers have two effects — the R&D disincentive effect and the inducement effect for firms to invest in own R&D efforts so as to absorb more of the spillover benefits. Cohen *et al*. (1990) show that the aggregate effect may stimulate firms to respond to higher spillovers by increasing own R&D spending. Following Spence (*op. cit*.) and Levin *et al*. (1988), firms may receive valuable information at a price that is below the cost of producing it internally or of acquiring it in the market. If such information is deemed to be a substitute to the firm's own knowledge, then the firm receiving the spillover benefits may invest less in R&D than it would without spillover effects. In this case we may observe a negative effect of spillovers on the firm's R&D expenditure. On the contrary, if spillovers are complementary so that we observe a positive effect of spillovers on the firm's R&D expenditure, then the spillovers receiving firm may engage in increased R&D efforts (once output effects have been controlled for). In both of these instances, access to spillovers is assumed to take place at negligible costs (Griliches, 1979).

[4] In the context of industry evolution it is argued that in early stages after the emergence of technically useful knowledge, firms may pursue complementary research activities so that R&D spillover should be a strategic complement to the firm's own R&D at this stage. However, over a span of time (a longitudinal time frame of over 10 years), the technical knowledge accumulated by one firm may become a substitute for other firms' ideas.

R&D initiating firms and therefore, a *positive* interaction of R&D and R&D spillovers can be expected. On the contrary, there might also exist a *negative* interaction between own R&D and spillovers received from other firms in the industry. This may happen if the firms are not familiar with spillovers generated from unrelated industry groups in which case the technological strategy of a company is not stressing the link between in house R&D and outside spillovers; or if, establishments with high R&D efforts are *closer* to the "frontier of technology" and are specialized firms and therefore, less willing to learn from outside. This negative interaction between firm's own R&D and spillovers supports the theoretical literature by Jovanovic *et al*. (1994) and Eeckhout *et al*. (2002).

Harhoff (1996) theoretically develops a model in which a monopolist may enhance downstream product innovation by creating knowledge spillovers which these (downstream) firms may use as a substitute for their own R&D efforts. This may in effect lead to greater downstream product quality, expand downstream firm's output and increase the demand for the upstream firm's intermediate goods. This may increase the aggregate industry R&D capital [Cohen *et al*. (1989)]. Several other authors in literature have empirically documented on the importance of spillovers on firms production structure and performance; for instance, Levin *et al*. (1984), with a cross section sample of manufacturing firms, estimated that a one percent increase in the R&D spillover caused the average cost of the recipients to decline by 0.05 percent. Jaffe (1986) examined a cross section sample of manufacturing firms and estimated that the profits of the spillover receiving firms increased by 0.3 percent when the spillover increased by 1 percent.[5] At the same time spillovers may generate free rider problem and that a firm's incentive to undertake R&D activity may diminish. There is however no empirical consensus as to whether R&D spillovers actually lower incentives.

A few prior studies empirically illustrating the impact of the spillover variable on different dependent variables, such as output, R&D spending, patents and average cost of production are mentioned in Table 1. Their empirical finding suggests heterogeneity in the role of spillovers.

The role of spillovers emanate from the various advantages that a knowledge revealing firm may experience. Given an alternative between hiding new ideas or making it public, it may pay off to reveal ones own knowledge. This may lead to diffusion that increases the likelihood of benefits obtained via a number of effects such as the network effects, reputational gains, and related innovations induced among other users. Other factors such as communal norms, altruism may play a strong role in inducing knowledge sharing in the fields such as the open source software. Programmers may feel incentivised by reciprocity to reveal their code because they have benefited from the code revealed by others (Harhoff *et al*., 2003).

[5] In theory, the importance of spillovers arise from the fact that the "input" derived from own R&D investment may in fact be positively influenced by the input "borrowed" from other sectors, [Griliches (1979)].

Table 1: Selected Empirical Studies on the Impact of R&D Spillovers on Technological efforts

Author	Sample and Data Period	Dep. Variable	Indep. Variable	Impact of the Spillover variable
Jaffe (1986)	Cross-sections of 432 manufacturing firms one centered on 1973 and another centered on 1979.	Patent count	R&D expenditure (R), spillover pool (S), Interaction between R and S, set of dummy variable for the technological cluster.	Positive and statistically significant effect of Spillover coefficient as well as the interaction term.
Jaffe (1988)	Cross-section of 537 firms for the year 1976	Annual R&D of the firm	Log Sales, log Capital Stock, Market share [sales weighted average market share], log spillover pool.	Positive and statistically significant effect of Spillover.
Levin *et al.*, (1988)	Cross section of 116 manufacturing firms for the year 1976.	R&D spending as a fraction of total production costs	Technological opportunity through upstream material supplier and equipment supplier, dummy variable for process technology, industry dummy, extent to which product is a consumer good, energy intensity of the product, spillovers from firms in related business lines.	No impact of Spillovers.
Bernstein *et al.*, (1989)	A panel of 48 firms from manufacturing industries for the period 1965-78.	Average cost	R&D capital, output, industry specific R&D capital from rivals, physical capital, labour	Negative and statistically significant impact of spillovers.
Harhoff, (2000)	A panel for 443 manufacturing firms for the period 1977-89.	R&D expenditure	Lagged R&D, contemporaneous and lagged terms for net sales and R&D spillovers, firm specific effects.	No effect of the contemporaneous spillover pool but positive and significant impact of lagged spillover pool.
Saxena, (2011)	Unbalanced panel of around 3000 firms from 11 manufacturing industries for the period 1994-2006	Real output	Net fixed assets, employment, raw material, R&D capital stock, stock of plant and machinery, equipment spillover, R&D spillover.	Technology and spillovers have a positive and significant impact.

Firm Size and R&D Efforts

Some innovations are so expensive that only large firms can finance and support them, due to the existence of fixed costs or economies of scale that allow one to spread the cost of R&D between more units of output (Cohen *et al.*, 1996). In addition, large firms can pool the risks and reduce aggregate risk by undertaking large number of projects; Kraft (1989). Empirical studies show that large firms are more innovative in industries which are more capital intensive and produce differentiated good [Acs *et al*. (1988)]. Concurrently there also exists a range of innovation which is not sought by small firms in the first place. For instance, "the competition in the chemical industry or turbine generators is mainly between various large or giant firms" [Freeman (1982)]. Thus the positive R&D−Size relationship across industries may be by chance due to the concentration of the largest firms in the more R&D intensive industries. In this state the argument for large firms as promoting R&D could be established if "among only the larger firms in an industry, the effort devoted to research and development increases more than in proportion to size" [Worley (1961)]. However, the studies examining the relationship between innovation and firm size have been constrained to a limited range of firm sizes, such as Fortune 500 [Scherer (1965)], and a limited number of industries [Mansfield (1963)].

It is argued that large firms are better qualified or perhaps more eager to undertake R&D than smaller firms for the following reasons. First, R&D is characterized by increasing returns to scale which a large firm can exploit better. Second, since R&D activity involves a high level of risk that is difficult to eliminate with insurance (for reasons of moral hazard), large firms may be more willing to take these risks as they can be diversified over a wider range of product lines. Third, the production pattern in a large firm is more systematic and routinized, which makes it easier for them to implement a new innovation.

The various empirical studies in the Indian context remain inconclusive as to the exact relationship between firm size and the innovative activity of the firm. For instance, Katrak (1989) concluded that R&D effort increases with firm size, but less than proportionately. Kumar and Saqib (1996) found that the probability of undertaking R&D activity increased with firm size up to a certain level after which it reduced. In contrast, Basant (1997) found a positive relationship between technological activity and firm size. In other studies on Indian manufacturing industries, Siddharthan and Safarian (1997) found market share to be an unimportant determinant of capital goods import. In a more recent study, Narayanan and Bhat (2009) suggest that the medium-sized firms are more R&D intensive than their smaller and larger counterparts. Their findings suggest that small sized firms are unable to invest on technological activities due to their limited resources, while their larger counterparts are mainly using their in-house R&D efforts to adapt imported technology to Indian conditions.

Age and R&D Efforts

Age of the firm represents the experiences and learning acquired by the firm over a period of time. It is possible that the younger firms are also the more innovative ones, as the foundation of a firm usually goes hand in hand with the introduction of one or more innovations. The established firms are often reluctant to introduce "fundamental" innovations like those launched by newly founded companies. The new firms are possibly also those that go into new markets. The empirical results are mixed. While Martinez-Ros (2000) found that the experience in product innovations encourages the process innovation probability by 36.3%, Thornhill (2006) found firm age to have a negative and significant effect on innovation.

The interaction between learning through R&D and learning through experience is an essential part of innovation process. With regard to the role of learning through spillover it is assumed to occur instantaneously. However, it requires experience and investment even for acquiring knowledge freely available in the public domain thereby rendering spillovers to have a significant impact on determining R&D intensity. Age of the firm is an indicator of firm's experience gained over the years. We test whether firms with longer years of experience spend more or less on R&D. We therefore determine the possible substitutability or complementarity between in-house R&D efforts and R&D Spillovers when experience of the firm interacts with the knowledge available outside the firm.

Technology imports and R&D Efforts

In order to undertake innovative activities firms take on various strategies that necessarily involve own indigenous R&D efforts either *complemented* or *substituted* by import of technology either in *embodied* or *disembodied* form or both. These technological opportunities may generate potential for undertaking adaptive R&D in which case firm's import technology and then invests in R&D. The firm may then use R&D efforts to adapt and develop imported technology; see, Ray and Bhaduri (2001) and Narayanan and Bhat (2009). However, if the firm's R&D activity is geared towards substituting for the imported technology as well as intermediate inputs we may expect a *negative* relationship between technology import and R&D. This may hold particularly for disembodied technology imports, while the former may be relevant for import of embodied technology.[6]

A number of studies for India and other countries have examined the relationship between R&D and technology imports. Studies on this aspect have found mixed results. Evidence from Japan (Odagiri [1983]) and India (Lall [1983], Katrak [1985], Siddharthan [1988], Kumar and Aggarwal [2005]) suggests that the relationship of complementarity dominates that of substitution. Also some sectors specific studies such as Katrak (1989) for the electrical and industrial machinery industries, Narayanan (1998) for the automobile industry and Pradhan (2002) for the pharmaceutical industry, among others found a complementary relationship. On the other hand, studies by Kumar (1987), Basant and Fikkert (1996), found substitution effect of technology import on domestic R&D. However, some studies, including, Katrak (1997), have found neither a substitution nor a complementary relationship between technology import and R&D.

Other firm and industry characteristics

Profitability: Innovation activities are difficult to finance in a competitive market setting with capital from sources external to the firm. Profits of a firm are an important determinant of the innovation decision because unless the innovative firm is already profitable, some innovations may not be financed adequately given the high cost of external finance. A firm may either borrow or may reinvest its profits. However firms may be unwilling to borrow substantial funds to finance new product or process development and hence only firms with substantial profit margins would be able to support in-house R&D effort. However there is no consensus in the empirical literature with respect to the effect of internal financing on innovative efforts. In the

[6] A greater dependence of a firm on imports of technology resulting in lower technological effort indicates *substitutability* and if foreign technology acts as a catalyst for domestic efforts in order to adapt the imported technology to local conditions, a *complementary* relationship is apprehended.

Indian context, Narayanan (2004) observed that firms in the Automobile sector were reinvesting their profits on technological sources in order to establish themselves.

Vertical Integration: Vertical integration might lead to reduction in technology purchase from the market against royalty payments and may have moderate effect on in-house R&D efforts. Cohen and Levin (1989) argue that a firm's higher degree of vertical integration may actually increase the amount of R&D undertaken, in the direction where there is possibility of exploiting economies of scope and diversifying. However, according to Lin (2003) vertically disintegrated industrial system with low entry barriers in China led to the formation of a strong electronics and information industry in Taipei.

Industry Concentration: Market characteristics, such as the degree of concentration and competition, have an important role in determining R&D intensity. The degree of market power has empirically been highlighted as a crucial determinant influencing R&D intensity, since it allows firms to prevent entry and maintain its market position. The Hirschman –Herfindahl index (HHI) is a commonly accepted measure of market concentration. Since the present study deals with a single industry, we have taken Hirschman–Herfindahl index for each year as a proxy for market power faced by each firm in respective years.

Against this backdrop, we *examine the relationship of in-house R&D efforts and R&D Spillovers within the Indian Electronics Goods Sector*. The role of spillovers emanate from the various advantages that a firm may own. One of them could be the advantages accrued to relatively older firms having years of experience and knowledge of the market. In order to test this, we examine the significance of the interaction effect of 'learning through R&D spillovers' and 'learning through experience' for an unbalanced panel of 63 Indian Electronic Firms for the period 2002-2014.

3. The Indian Electronics Industry: An Overview

The Electronics Industry in India began its journey around mid-1960s with an orientation towards space and defence technologies rigidly controlled and initiated by the central government. During the period 1960s to late 1970s, the defence sector was the primary focus area for India's electronics sector. Much of the indigenous product development was aimed at satiating the demand for military equipments. Then 1980s saw the birth of India's consumer electronics market beginning with the indigenous development of televisions and telephones. Since mid-1991 onwards extensive economic and structural reforms have been carried out in India with major emphasis on facilitating external trade and boosting efficiency and productivity of domestic firms.

With the implementation of ITA-I under WTO with effect from March 1, 2005 the custom duty on all the specified 217 items has been eliminated. Industrial licensing has been abolished in the Electronics and Information Technology sector except for manufacturing electronic aerospace and defence equipment. Special schemes such as Export Oriented Unit Scheme, Electronics Hardware Technology Park Scheme, Software Technology Park Scheme are available for setting up Export Oriented units for the Electronics sector. In order to attract investors, incentives provided by the GOI include subsidy of up to USD 10 million per 100 acres of project in electronics manufacturing clusters, reimbursement of excise duties for capital equipment in non-SEZ units, no central taxes and duties for 10 years in high tech facilities such as semiconductor fabricating units, 2-5% of duty credit on exports of different products, and proposal to set up an electronics development fund worth USD 2 billion to promote innovation, R&D, product commercialization, and nano-electronics.

Pressure on the electronics industry remained though growth and developments have continued with digitalisation in all sectors, and more recently the trend towards *convergence of technologies*. At the same time the industry had to depend on import of technology for expansion of production. Liberalization of the economy encouraged the entry of multinational companies resulting in the reduction of the concentration ratio.

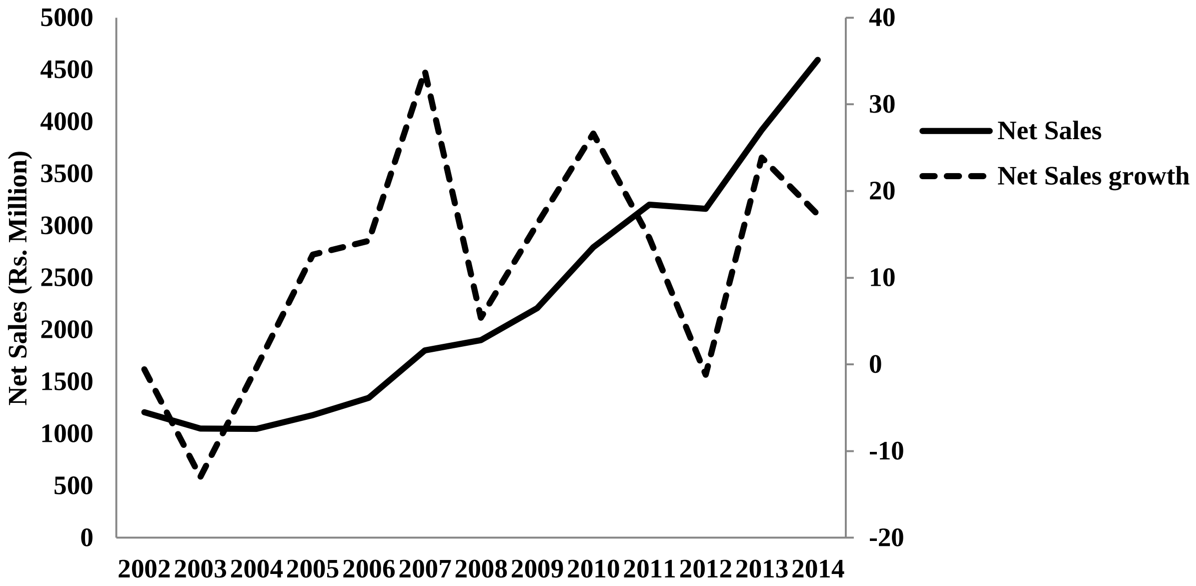
As seen from Table 2 and Figure 1, the net sales growth rate has fluctuated in the second phase of economic reforms. The growth rate has picked up in 2003 but decelerated at the onset of 2007-08 financial crises. On an average the annual growth rate has been around 11% in the Electronics industry. However, the pattern of net sales growth observed during 2002-2014 is that periods of high growth were invariably followed by periods of low growth. In order to minimize the negative influences due to economic (and political) problems in the rest of the world, the focus of the India's planning strategy is to look at the home market that provides a lucrative space for the growth of the industry.

Table 2: Net Sales and growth in Net Sales of Electronic firms in India, 2002-2014

Year	No. of Firms	Net Sales (Rs. Million)	Growth rate
2002	139	1206.27	-0.57
2003	170	1049.48	-12.99
2004	184	1045.32	-0.39
2005	182	1177.81	12.67
2006	182	1345.74	14.25
2007	177	1801.38	33.85
2008	179	1898.67	5.40
2009	172	2206.35	16.20
2010	163	2794.05	26.63
2011	139	3201.18	14.57
2012	129	3163.41	-1.17
2013	109	3918.83	23.88
2014	93	4595.79	17.27

Data Source: Prowess Database, Centre for Monitoring Indian Economy

Figure 1: Net Sales and Net Sales Growth in Indian Electronics Industry



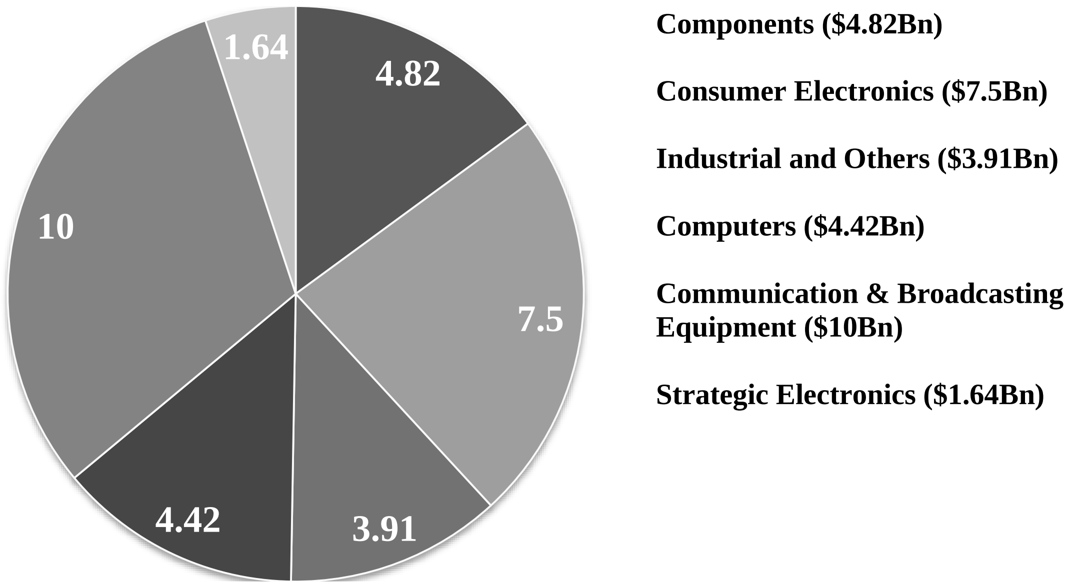
Data Source: Prowess Database, Centre for Monitoring Indian Economy

In order to exploit the large and varied industry size, market leaders like Solectron, Flextronics, Jabil, Nokia, Elcoteq have made large investments to access the Indian market. In consumer electronics Korean companies such as LG and Samsung have made commitments by establishing large manufacturing facilities and now enjoy a significant share in the growing market for products such as Televisions, CD/DVD Players, Audio equipment and other entertainment products. The growth in the telecom products demand has been tremendous and presently India is adding 2 million mobile phone users every month.

Apart from the presence of global Electronics Manufacturing Services (EMS) majors in India and their plans for increased investments in India, some of the growth drivers in this industry are R&D in design and engineering services, highly talented workforce and rise in outsourcing of professional and counselling jobs.

The electronic industry in India constitutes just 0.7 per cent of the global electronic industry. The domestic market in India is very attractive from the point of view of the electronics sector, and current trends indicate high growth potential for the sector in the future. The demand in the Indian market in 2008-09 stood at USD 45 Billion and is expected to reach USD400 Billion by year 2020. At the current rate of growth domestic production can cater to only USD 100 Billion by year 2020, thereby creating a demand supply gap of nearly USD 300 Billion.

Fig. 2: Indian Electronic Industry, 2012-2013



Source: ELCINA Directory of Indian Electronics Industry, 2012-13
Website: http://www.elcina.com/industry_size.asp

The Indian Market demand has a potential of creating USD 400 Billion market size. The buyer's demand is concentrated towards hardware equipment/components, design and services. This reflects a huge opportunity for both the domestic as well as the global electronics industry by catering to the Indian market. The gap between electronics hardware production and demand for electronic products has been growing over the last few years, because while production has grown at 10-12% per year demand has been racing ahead at near 25% every year.

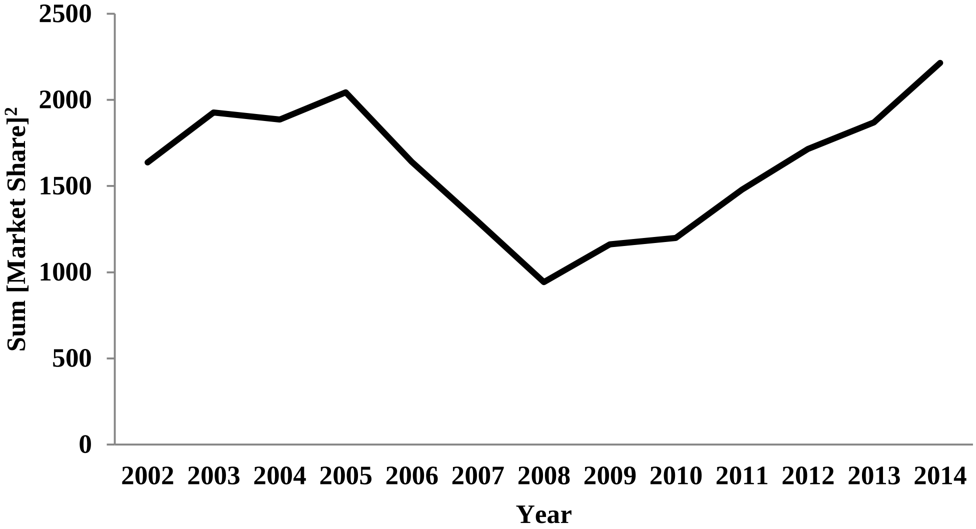
There is a significant local demand and rising manufacturing costs in alternate markets. Market for white goods[7] and televisions has been growing at close to 14% per annum, and is expected to accelerate to close to 17% in the coming years. The market for white goods and televisions has been growing but remains underpenetrated [Ernst & Young Report, 2015][8]. 65% of the current demand for electronic products is met by imports. There has been a rise in imports from low-cost regions such as China and South-East Asia due to various free trade agreements and availability of products at a lower cost as compared to costs incurred in local manufacturing. Major Indian and global consumer durables companies have announced investments of around US$1.4 billion over the coming years in India. Consumer electronics is expected to be US$29 billion market by 2020 from US$10 billion currently. Consumer electronics exports were projected to be INR64 billion in FY13 while the industry achieved INR16 billion. Hence, there is a considerable gap in output to be met by the Indian electronics industry.

[7] Refers to AC, washing machines and refrigerators

[8] Study on Indian Electronics and consumer durables segment (AC, refrigerators, washing machines, TVs), Ernst and Young Report, April 2015.

The concentration of electronics industry has shown a rapid decrease during the second phase of economic reforms; it gradually picked up after the 2007-2008 financial crises due to exit of firms. Figure 3 graphically represents the Hirschman Herfindahl index for the Electronics goods sector in India.

Fig. 3: Hirschman Herfindahl Index [HHI] in the Electronic goods Sector in India



Data Source: Prowess Database, Centre for Monitoring Indian Economy

The fluctuation in HHI is the result of the decline in the concentration in the communication electronics segment, followed by the component, computer and the industrial electronics. The consumer electronics industry is the only industry which, comparatively, remained constant.

4. Data and Variables

In order to explore the possible determinants of R&D intensity within the Indian Electronics firms, annual firm level data are collected from the CMIE Prowess database at the NIC-5 digit classification level. Given our objective, we consider only those firms that report R&D expenditure at least once during our sample data period 2002-2014.

Although the Electronics industry is reported to have 304 firms (as per CMIE database), our screening with R&D expenditure left us with only 102 firms. Data unavailability and instances of a firm reporting other independent variables in some years, while the data not reported for the same firms in other years generated an unbalanced panel of 73 firms. Further, we also excluded those firms where measured spillover value equals zero. That is, we did not consider a firm that existed in isolation in a particular industry group for any year during the 13 year data period. This gave us an unbalanced panel of 63 firms.

Table 3: Sample Description

Data Period	2002-2014
Number of R&D reporting firms taken in panel (unbalanced)	63
Number of observations	349
Average R&D intensity across cross sectional units and over the time period 2002-2014	0.02
Average Size Distribution over time	
Small and Medium [a]	87%
Large	13%
Average Age Distribution over time	
2 to 20	39%
21 to 40	42%
41 and above	19%

[a] Calculated by standardizing the net sales with deviation from average net sales (measured across cross sectional units and over time) of 4050 million and dividing by the average standard deviation of 1524.

Our econometric estimation is therefore based on the dataset of 63 firms for the 13 year period, 2002-2014. We have a total of 349 observations for this time period with no missing values of other independent variables. Table 3 describes the sample taken for study.

Variables and Measurement

Dependent Variable

Research Intensity-
We define R&D intensity of an incumbent undertaking R&D investment in a given year as R&D expenditure divided by (nominal) net sales.

$$\text{R\&D Intensity: } \left[\frac{\text{R\&D Expenditure}}{\text{Nominal Net Sales}}\right]_t$$

Independent Variables

Measuring Spillovers

There are various ways of constructing spillovers in literature. Some studies use either R&D or patents as the proxy for aggregate spillover stock. For instance, Levin *et al*. (1988) model the stock of industry knowledge available to firm *i* as,

$$X_i = x_i + \omega_x \sum_{j \neq i}^{N} x_j$$

Where X_i is the spillover pool available to the i^{th} firm, x_i and x_j are the R&D expenditure taken by the i^{th} and the j^{th} firm respectively and ω_x is a scalar parameter representing the extent of

R&D spillovers. N is the number of firms in the industry.[9] This formulation is based upon the assumption that the R&D of all other firms is equally valued.

Jaffe (1988) model the technological closeness of firms with implications on the impact of R&D undertaken by one firms on the spillover pool available to the neighbour firm. Jaffe (*ibid*.) assumes that each firm has at its disposal a "pool" of research results that have "spilled out" from other firms. These *results are more useful the more closely related are the firm's research interest*. The relevant spillover pool for each firm is the weighted sum of all other firms' research, where weights depend on the proximity of the firms in the technology space.[10] The potential spillover pool for the i^{th} firm is $S_i = \sum_{j \neq i} P_{ij} R_j$, where P_{ij} is the technological proximity of firm *i* and firm *j*.[11]

Spillovers in other works, such as Bernstein *et al*. (1988, 1989) were measured on the basis of the total R&D spending in the industry. Their spillover construct assumes that any firm has the same possibilities of gaining access to the stock of spillovers in the industry in which it operates. In order to estimate the net stock of spillovers to which the firm has access, the amount of investment in R&D by the firm itself was deducted from the aggregate stock of R&D expenditure by other firms so that the stock of available spillover pool is given as:

$$SPILL_i = \sum_{j=1}^{n} RD_j - RD_i$$

where $SPILL_i$ is the level of spillovers enjoyed by firm *i*; RD_j is the investment in R&D by the j^{th} firm and RD_i is the investment in R&D by the i^{th} firm.

Cohen *et al*. (1989) develop a model where R&D investment is necessary to acquire external knowledge. This in house R&D investment defines the absorptive capacity of the firm. They observe that increases in the extent of spillovers may also increase R&D. The relationship between firms stock of technological knowledge and own and other firms R&D investment is expressed as:

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9 If ω_x is set to zero, we obtain the specification used in Dasgupta *et al*. (1980). Levin *et al*. (1984) modelled this possibility with a variant of the above equation in which the degree of substitution between own and rival R&D was constrained by setting $\omega_x = 1$

10 To measure the proximity of two firms *i* and *j*, Jaffe (1988) use the uncentered correlation or angular separation of the vectors f_i and f_j where the f vector is the i^{th} firm's technological position vector which indicates the fraction of the firm's research effort devoted to the K diverse technological areas. The proximity measure P_{ij} is given by $\frac{(f_i f_j^{'})}{\sqrt{[(f_i f_i^{'})(f_j f_j^{'})]}}$.

This proximity measure ranges between zero and one, depending on the degree of overlap of the firms' research interests.

11 Harhoff (2000) employed similar proximity measure to compute the spillover pool for German manufacturing firms across 34 different product areas.

$$R_i = Z_i + c_i(\theta \sum Z_j + A)$$

where R_i represent the ith firms stock of technological and scientific knowledge, Z_i and Z_j are the ith firm's and the other j firms investment in R&D; c_i is the fraction of knowledge in the public domain that the firm is able to assimilate and exploit which represents the firm's absorptive capacity; θ is the degree of intra-industry spillovers; and A is the level of extra-industry knowledge. The degree to which the research effort of one firm may spill over to a pool of knowledge potentially available to all other firms is characterised by θ where $0 < \theta < 1$. Exogenous factors such as patent policy shape θ. The model postulates that a firm's capacity to absorb externally generated knowledge depends on its R&D effort with $0 < c_i < 1$.

For the present estimation purpose we assume $\theta = c_i = 1$; that is, the R&D effort of an innovating firm increases the pool of knowledge and ideas available to other firms by the total amount of the other firm's R&D and that firms absorb all available knowledge that is in the public domain. Therefore we take the aggregate of the R&D expenditure undertaken by firms in related industry groups normalized by their net sales as a measure of R&D spillovers available to a R&D undertaking firm. This implies that we equate Jaffe's (*ibid*.) proximity measure between firms denoted by P_{ij} to equal 1. We take this industry group level aggregation on the basis that we are analysing here only one industry under the assumption that all firms within the industry would always operate exclusively in one and the same product area.

A similar construction can be seen in Martinez-Ros (2000) where spillovers are measured by the industry knowledge stock minus the own firm R&D expenditure normalised by the industry sales net of firm's sales. Following Griliches (1979), we apprehend that *firms which are closely related in the sense of falling in the same industry group classification are presumed to benefit more from each other's R&D efforts* than firms at greater distance from each other.[12] Such a construction may not be appropriate in the case of analysis involving more than one industry, in which case both horizontal and vertical borrowing of ideas and new knowledge need to be considered for measuring proximity and calculating the spillover pool. According to Griliches (*ibid*.), "true spillovers are the ideas borrowed by the research teams of industry *i* from the research results of industry *j*". Access to new knowledge or information through R&D Spillovers may reduce the incentive to invest in R&D. At the same time it also reduces the R&D required to achieve a given level of cost reduction for agents absorbing the benefits of such spillovers.

The proxy for R&D spillovers available to a R&D undertaking firm is the aggregate of the R&D expenditure undertaken by firms in related industry groups normalized by their aggregate net sales[13].

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[12] As perceived by Griliches (1979), "The problem arises when we want to extend this scale across the other … industries. Here there is no natural order of closeness (e.g., is "leather" closer to "food" or to "textiles"?)."

[13] We analyze the role played by "incoming spillovers" and their interaction with the "experience" of the receiving firms. We have taken a one year lag in order to look at the role of R&D spillovers in determining the R&D efforts of the firms. As regards the level of the spillover pool accessible to a firm,

Therefore,

$$\text{R\&D Spillovers} = \frac{\sum_{j=1}^{n} \text{RD}_j}{\sum_{j=1}^{n} \text{Net Sales}_j} \quad \text{where } j \neq i$$

Measuring other Explanatory Variables

Age: Current year – Year of Incorporation.

$$\text{Profitability: } \left[\frac{\text{Profit after tax}}{\text{Nominal Net Sales}}\right]_t$$

Firm size: Log of Net sales of firm [*ln* NS]

$$\text{Embodied Technology: } \left[\frac{\text{Expenditure on import of capital goods}}{\text{Nominal Net Sales}}\right]_{t-1}$$

$$\text{Disembodied Technology: } \left[\frac{\text{Expenditure on royalty \& know-how}}{\text{Nominal Net Sales}}\right]_{t-1}$$

$$\text{Vertical integration: } \left[\frac{\text{Value added}}{\text{Nominal Net Sales}}\right]_{t-1}$$

Industry concentration: The Hirschman Herfindahl Index [HHI] is expressed as,

$$\text{HHI} = \sum_{i=1}^{n} (\text{Market Share})_i^2 .$$

The HHI number can range from close to zero to 10,000. The closer a market is to being a monopoly, the higher the market's concentration (and the lower its competition).

The interaction term:

R&D spillovers and age: $[\text{R\&D Spillovers} \times \text{Age}]_{t-1}$

Table 4 defines the variables and provides the abbreviation included in the analysis.

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we follow the model of within-industry spillover effects by Griliches (1979). This measurement is complicated when we do not deal with one industry. Jaffe (1986) identifies the technological distance of the firms in terms of the "research activity of its neighbours in technology space" and use it to measure spillovers. This technological distance measure the "closeness" of industries proportional to their purchases from each other or as taken in Jaffe (1986), by the closeness in research interest.

Table 4: Description of the Variables

Variables	Definition	Abbreviation
Dependent Variable		
R&D Intensity	R&D expenditure divided by Net sales, in the current period.	RDI
Independent Variables		
R&D Spillover$_{t-1}$	Aggregate stock of R&D expenditure from technological neighbours.	RDS
Age$_{t-1}$	Age of firm *i* in year t-1 computed as the difference in age at t-1 and the year of incorporation.	AGE
Interaction Term	Product of R&D Spillovers and age of firm *i*.	$[RD_S \times AG]_{t-1}$
Size$_t$	Log of Net sales of firm *i*.	NS
Profit Margin$_t$	Profit after tax in year t divided by net sales.	PM
Embodied Technology$_{t-1}$	Payments towards import of capital goods divided by Net Sales.	ET
Disembodied Technology$_{t-1}$	Payment towards royalty and technical knowhow divided by net sales.	DT
Vertical Integration$_t$	Ratio of value added by Net sales.	VI
Herfindahl Index$_t$	Aggregate of the square of market share of all the firms.	HHI

5. Descriptive Statistics

Table 5 and Figure 4 describe the pattern of R&D intensity in an unbalanced panel of 63 firms belonging to the Indian Electronics industry for the study period, 2002-2014.

As seen in Table 5 and observed in Figure 4, R&D intensity has a positive trend and has increased from less than 0.73% in 2002 to approximately 5.8% in 2014. The average annual R&D intensity is measured to be approximately 2% over the time period 2002-2014.

Table 5: Descriptive Statistics of R&D intensity and R&D Spillovers for the period 2002-2014

Year	Average R&D intensity	Std. Dev	Average R&D Spillovers	Std. Dev
2002	0.73	0.9	1.6	2.3
2003	0.9	1.06	1.5	1.8
2004	0.98	1.14	2.09	2.7
2005	2.45	4.5	10.1	18.1
2006	2.1	2.8	2.9	4.3
2007	1.2	1.3	1.4	2.3
2008	1.7	2.5	0.9	0.9
2009	1.9	2.4	1.3	1.4
2010	1.8	2.1	1.5	1.5
2011	2.1	3.3	1.9	1.8
2012	2.7	4.5	2.5	2.3
2013	2.8	4.3	2.6	2.4
2014	5.8	12.1	4.6	7.5

Fig. 4: Average R&D Intensity of electronic goods sector in India

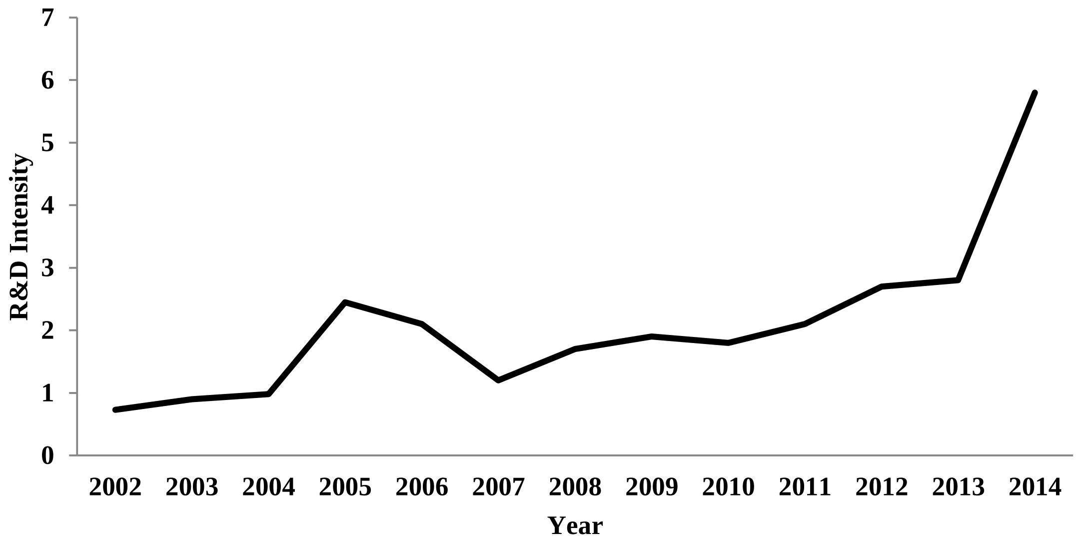

Figure 5 show the trend of R&D intensity and R&D Spillovers during the 13 year period. On an average the graph of R&D Spillovers lies above the R&D trend during the same period.

Fig. 5: R&D Intensity and R&D Spillovers of electronic goods sector in India

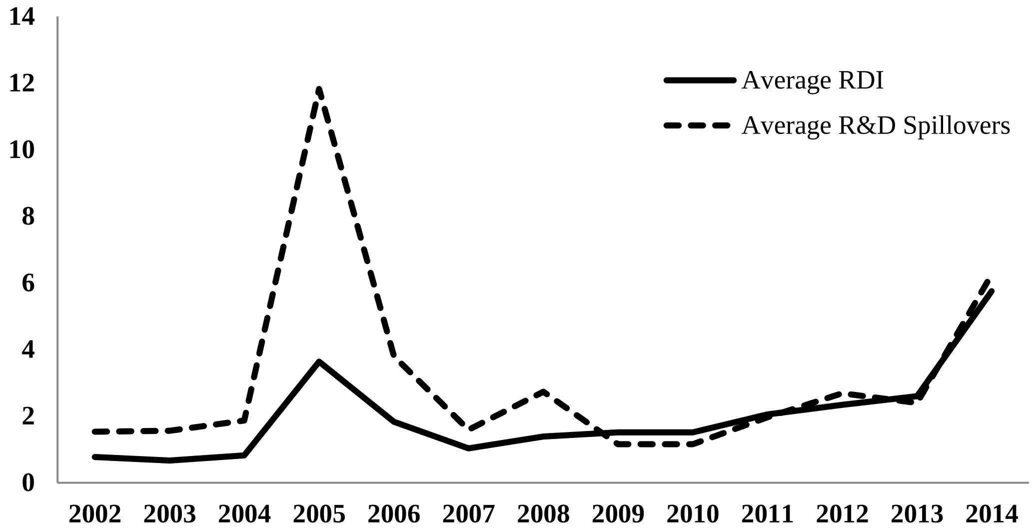

Figure 6 provides a graphical representation of average R&D intensity and R&D Spillovers for the 12 industry groups within the Indian Electronics Goods Sector. As observed from the bar diagram maximum R&D Spillovers of approximately 8.5% is experienced by NIC 5 digit industry group 26302 which is the communication and equipment industry. The highest recorded R&D intensity is seen for the industry with NIC code 26405 which is the 'Other Electronics' industry group manufacturing Electronic buzzers, soft ferrites, amplifiers etc.

Fig. 6: Average R&D Intensity and R&D Spillovers for the 12 industry groups

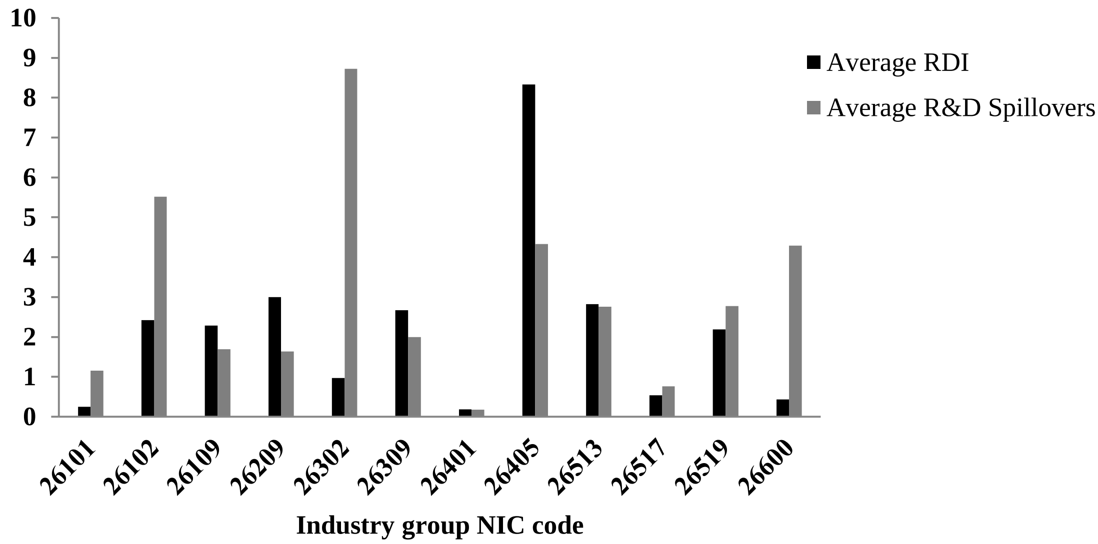

Table 6 shows summary statistics for the sample of firms considered in the estimation exercise. As observed from the table, the mean age of the firms in this industry is 26. Given the average age distribution across the panels, the sample has a high proportion of middle aged firms.

Table 7 presents the pair-wise correlation coefficient of the independent variables used in the present analysis. As can be seen, age is positively correlated to Net sales, and negatively correlated to profitability.

Table 6: Descriptive Statistics of the Variables

Variable	Mean	Std. Dev.	Min.	Max.	No. of firms	No. of observations
R&D intensity	1.94	3.71	0	45.41	63	349
Age (in years)	26.92	12.25	6	60	63	349
Net Sales (in Rs. Millions)	4055.28	8929.80	6	62161.20	63	349
Profitability	-7.77	129.33	-1802.26	385.99	63	349
R&D Spillover	2.56	6.05	0.007	78.57	63	349
Disembodied Technology	0.46	1.02	0	5.81	63	349
Embodied Technology	1.76	4.77	0	57.22	63	349
Vertical Integration	39.99	21.55	-47.03	96.21	63	349
HHI	1550.07	374.46	941.87	2215.65	63	349

Thus, the firms that are large are also the ones who are experienced. Age is negatively correlated with R&D Spillovers. However it is statistically insignificant. Firm size measured by net sales is negatively and significantly correlated with HHI and vertical integration. This would imply that small size firms prevail in a relatively competitive environment with lower degree of vertical integration.

Table 7: Correlations matrix

	Age	R&D Spillover	Net Sales	Profit	HHI	Disemb. Tech	Embod. Tech.	Vertical Integ.
Age	1							
R&D Spillover	-0.06	1						
Net Sales	0.15^{***}	0.01	1					
Profit	-0.12^{**}	-0.01	0.08	1				
HHI	-0.01	0.22^{***}	-0.14^{***}	0.004	1			
Disemb. Tech	-0.003	-0.03	0.12^{**}	0.005	0.09	1		
Embod. Tech.	-0.13^{**}	-0.01	0.08	0.02	-0.02	0.11^{**}	1	
Vertical Integ.	-0.01	-0.02	-0.25^{***}	0.11^{**}	0.05	0.09	0.05	1

*, ** and *** denote significance at 10% , 5%and 1%, respectively

6. Estimation Methodology

The dependent variable in this analysis is R&D intensity, derived from the values of R&D expenditure reported by firms as a proportion of net sales, and the model employed to explain the variation in inter-firm R&D intensity is the one-way Fixed Effects model. The econometric model, defined as Model I is given as the following:

$$\text{RDI}_{it} = \alpha_i + \beta_1\text{Size}_{it} + \beta_2\text{Age}_{it} + \beta_3\text{Profitability}_{it} + \beta_4\text{HHI}_{it} + \beta_5\text{Disembodied Tech}_{it-1} + \beta_6\text{Embodied Tech}_{it-1} + \beta_7\text{Vertical Integ}_{it} + \beta_8\text{R\&D Spillovers}_{it-1} + \beta_9[\text{D}_{IG} \times \text{R\&D Spillovers}_{it-1}] + ... + \beta_{19}[\text{D}_{IG} \times \text{R\&D Spillovers}_{it-1}\}] + \varepsilon_{it}$$

where RDI is R&D intensity of the i^{th} firm, and D_{IG} are the dummy variables for the 11 industry groups forming our sample. We have incorporated one less dummy (12 industry groups-1) in order to avoid the dummy variable trap.

We also estimate Model I with interaction effect [specified as Model II] by introducing an interaction term of R&D spillover considered interacting with the age of the firm. In this case the econometric model specification is,

$$\text{RDI}_{it} = \alpha_i + \beta_1\text{Size}_{it} + \beta_2\text{Age}_{it} + \beta_3\text{Profitability}_{it} + \beta_4\text{HHI}_{it} + \beta_5\text{Disembodied Tech}_{it-1} + \beta_6\text{Embodied Tech}_{it-1} + \beta_7\text{Vertical Integ}_{it} + \beta_8\text{R\&D Spillovers}_{it-1} + \beta_9\{\text{Age} \times \text{R\&D Spillovers}\}_{it-1} + \beta_{10}[\text{D}_{IG} \times \{\text{Age} \times \text{R\&D Spillovers}\}_{it-1}] + ... + \beta_{20}[\text{D}_{IG} \times \{\text{Age} \times \text{R\&D Spillovers}\}_{it-1}] + \varepsilon_{it}$$

The Fixed Effects Method

The one-way fixed effects model allows each cross-sectional unit to have a different intercept term though all slopes are the same, so that

$$Y_{it} = \alpha_i + x'_{it}\beta + \varepsilon_i \qquad (1)$$

Where the individual-specific effects $\alpha_1, \alpha_2, ..., \alpha_N$ measure firm level unobserved heterogeneity that is possibly correlated with the regressors, x_{it} and β are $K\times1$ vectors, and the errors ε_{it} are *iid* $[0, \sigma^2]$.

For practical purposes we are interested in the K slope parameters β, which give the marginal effect of change in regressors since $\partial E[y_{it}]/\partial x_{it} = \beta$. The N parameters $\alpha_1, \alpha_2, ..., \alpha_N$ are incidental parameters that are not of intrinsic interest. However, their presence potentially prevents estimation of the parameters β that are of interest.

Fixed Effects Estimator

The within model is obtained by subtraction of the time-averaged model $\bar{y}_i = \alpha_i + \beta\bar{x}_i' + \bar{\varepsilon}_i$ from the original model. Then

$$y_{it} - \bar{y}_i = (x_{it} - \bar{x}_i)'\beta + (\varepsilon_{it} - \bar{\varepsilon}_i) \qquad (2)$$

So the fixed effect α_i is eliminated, along with time-invariant regressors since $(x_{it} - \bar{x}_i) = 0$ if $x_{it} = x_i$ for all *t*.

Using OLS estimation yields the within estimator or fixed effects estimator $\hat{\beta}_w$, where

$$\hat{\beta}_w = [\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \bar{x}_i)(x_{it} - \bar{x}_i)^{'}]^{-1}\sum_{i=1}^{N}\sum_{t=1}^{T}(x_{it} - \bar{x}_i)(\mathrm{y}_{it} - \bar{y}_i) \qquad (3)$$

The individual fixed effects α_i can then be estimated by

$$\hat{\alpha}_i = \bar{y}_i - \bar{x}_i^{'}\hat{\beta}_w, \quad i = 1,..., N \qquad (4)$$

The estimate $\hat{\alpha}_i$ is unbiased for α_i , and it is consistent provided *T* tends to infinity since $\hat{\alpha}_i$ averages T observations. The α_i are viewed as ancillary parameters that do not need to be consistently estimated to obtain consistent estimates of the slope parameters β .

In the fixed effects model, the effect of each predictor variable (i.e., the slope) is assumed to be identical across all the groups, and the regression results report the average within-group effect.

6.1 Empirical Results

Tables 8.1 & 8.2 represents the parameter estimates of the two models where we hypothesize that firms' (current) R&D intensity is determined by firm size, profitability, age, R&D Spillovers and embodied and disembodied technology, industry concentration, and degree of vertical integration. We introduce slope dummies in order to test whether inter industry differences have similar impact of R&D Spillovers on firm level R&D intensity. In Model I, we allow the slope coefficient of Spillovers to vary between industries, while in Model II the slope coefficient of the interaction term [Age $\times$ R&D Spillovers] is varied across the industry groups. With specific slope dummies, the marginal effects of the significant slope coefficients are calculated and represented in Table 9.

The results are as follows:

(1) The coefficient of R&D spillovers is negative and statistically significant in Model I. The negative sign suggests substitutability between R&D Spillovers and in-house R&D efforts. This imply as a possibility that firms have the technology option available to take on own R&D efforts vis-à-vis similar technology available through spillovers. The negative coefficient states that the research oriented firms that have an access to outside knowledge, and possess sufficient in-built expertise may prefer to exploit the readily available technology from similar or related industry categories instead of investing in own in-house R&D activities. It indicates that the firms within the Indian Electronics industry undertake innovation which is observed and visible to competitors rather than

innovation where secrecy may block the technology of design or process to be accessed by others.

Table 8.1: Results of Fixed Effects estimation for R&D intensity as the Explained variable

Variables	**Model I**	**Model II: Model I with interaction effect**
R&D $Spillover_{t-1}$	-0.107 [*-4.66*]***	0.05 [*1.12*]
Age_{t-1}	0.003 [*1.72*]*	0.003 [*1.75*]*
$[Age \times R\&D\ Spillover]_{t-1}$		-0.007 [*-2.69*]***
$Size_t$	-0.01 [*-1.80*]*	-0.01 [*-1.67*]*
$Profitability_t$	0.00001 [*0.55*]	0.00001 [*0.79*]
Embodied $Technology_{t-1}$	0.01 [*0.61*]	0.007 [*0.40*]
Disembodied $Technology_{t-1}$	-0.42 [*-1.23*]	-0.43 [*-1.24*]
Vertical $Integration_t$	-0.03 [*-1.80*]*	-0.03 [*-1.82*]*
HHI_t	8.11e-06 [*1.06*]	8.32e-06 [*1.11*]
Constant	-0.01 [*-0.34*]	-0.01 [*-0.51*]
No. of Firms	63	63
No. of Observations	349	349
R^2 within	0.14	0.15
F(19,62)	(30.81)***	
F(20,62)		(4.32)***

*, ** and *** denote significance at 10% , 5%and 1%, respectively

(2) Age of the firm has a positive and statistically significant effect on R&D intensity. This implies that the older firms that have been in production for several years have a greater intensity to undertake in-house R&D activities on account of the accumulated learning that carries possibility for further technological activity. The information advantage to the aged firms is posited to influence R&D intensity favourably. Accumulation of technology over a long period of learning process provides the firms with comparative advantage over the new entrant. As a result firms with their accumulated 'learning-by-doing' could be in an advantageous position.

As R&D Spillovers and age of the firm emerges as significant determinants of R&D intensity, we additionally test whether the accumulated knowledge provides a more favorable position to the older firms in reaping information and know-how from related industry groups. This is carried out by introducing an interaction term where the age of the firm interacts with R&D Spillovers accrued to the firm. The result is shown in Model II, presented in Table 8.1.

(3) The coefficient of the interaction term in Model II is negative and statistically significant. When R&D Spillovers are considered interacting with the experience of the firm, R&D spillovers emerge as a substitute to R&D efforts. That is, the older firms have a relatively greater ability to exploit the information and know-how from related industry groups through their cumulated expertise attained through past R&D investment which developed their absorptive capacity. In the context of the Indian Electronics industry, both the young and the older firms require new knowledge or ideas from beyond its boundaries in order to remain competitive. As a consequence, the incumbents in this industry rely on spillovers through R&D activities by other firms within the same industry or from cooperative modes such as joint ventures or mutual exchanges of technical know-how. In the Electronics goods sector in India, these spillovers can be easily exploited by the older firms that have already invested in building its in-house expertise in exploiting know-how from related industry groups. The revelation of one's own knowledge leads to diffusion that increases the likelihood of benefits obtained via a number of effects such as the network effects and reputational gains that may be more readily experienced by the older firms.

(4) Introducing slope dummies for R&D Spillovers rules out the assumption that slope of the regression line is the same for each industry category for this variable. That is, we test whether a negative and significant coefficient of R&D Spillovers (as in Model I) and a negative and significant coefficient of the interaction term (as in Model II) are established for all the industry groups within the Indian Electronics sector. The coefficients of the slope dummies (shown in Table 8.2) and the calculated marginal effects (in Table 9) show that while substitutability between R&D efforts and R&D Spillovers holds true for nine industry groups, it is weak for two industries (Other Electronics_2 and Other Electronics_4). Also industry groups, such as the Other Electronics_1 and Communication Equipment industry demonstrate complementarity between in-house R&D efforts and R&D Spillovers. Similarly, varying the coefficient of the interaction term across the industry groups reveals that the Other Electronics_1 industry group show weak complementary relationship between R&D activities and R&D Spillovers.

Table 8.2: The slope coefficients of R&D Spillovers and the interaction term in Models presented in Table 8.1

S. No.	Variables	Model I	Model II: Model I with interaction effect
1.	Other Electronics$_1$ [*26101*]	0.16 [*1.93*]*	0.008 [*2.10*]**
2.	Other Electronics$_2$ [*26102*]	0.10 [*1.83*]*	0.006 [*2.81*]***
3.	Other Electronics$_3$ [*26109*]	0.01 [0.16]	0.003 [*1.76*]*
4.	Computers, Peripherals & Storage Devices [*26209*]	-0.22 [-*2.95*]***	-0.01 [-*3.65*]***
5.	Communication Equipment$_1$ [*26302*]	0.12 [*5.46*]***	0.003 [1.16]
6.	Communication Equipment$_2$ [26309]	-0.10 [-0.59]	0.0001 [0.03]
7.	Consumer Electronics [26401]	-3.42 [-1.43]	-0.16 [-1.35]
8.	Miscellaneous Manufactured Articles$_1$ [26513]	0.09 [0.99]	0.004 [0.92]
9.	Other Electronics$_4$ [26517]	0.12 [0.71]	0.003 [0.53]
10.	Miscellaneous manufactured Articles$_2$ [*26519*]	-0.61 [-*2.45*]**	-0.01 [-*2.16*]**
11.	Other Electronics$_5$ [*26600*]	0.10 [*4.24*]***	0.006 [*3.21*]***

*, ** and *** denote significance at 10% , 5%and 1%, respectively

Table 9: The Marginal Effects for Slope Dummies

Industry Group	Model I	Model II
Other Electronics$_1$ [*26101*]	0.053	0.001
Other Electronics$_2$ [*26102*]	-0.007	-0.001
Other Electronics$_3$ [*26109*]		-0.004
Other Electronics$_4$ [*26600*]	-0.007	-0.001
Computers, Peripherals & Storage Devices [*26209*]	-0.327	-0.017
Communication and Equipment [*26302*]	0.013	
Miscellaneous manufactured Articles [*26519*]	-0.717	-0.017
Overall	*-0.107*	*-0.007*

(5) The often told argument in the empirical literature is that large sized firms have a scale advantage in undertaking R&D activities because of their capability to mobilise resources involved in research (Kumar *et al.*, 1996). However, in our study, we find firm size to have a *negative* impact on R&D intensity. The coefficient value is stable in the two models. This is in contrast with the Ray and Bhaduri (2001), among others. Ray and Bhaduri (*ibid.*) used cross section data of electronics industry and estimated their models using OLS and Tobit model while our study estimates a one-way fixed effects model having an unbalanced panel confined to electronics firms only. We suspect that since the data period of our study is restricted to the second generation economic reforms, our sample selection is therefore, biased towards the small and young electronic firms and hence the negative coefficient for the size variable.

    To put it succinctly, a large firm size lowers the incentive to undertake R&D efforts. A possible explanation to this could be that smaller firms are relatively more dynamic than their large counterparts in investing in varied technological strategies and hence require sufficient in house R&D skills in order to learn and adapt the available technology to local conditions. The large and the old firms already possess the absorptive capacity through earlier R&D efforts and concentrate more on exploiting the available information than engaging further in in-house R&D efforts.

(6) The coefficient of vertical integration is statistically significant with a negative sign. Firms with higher levels of vertical integration may not be engaged in in-house R&D activities. This result is in contrast to Armour and Teece (1980), who argue that vertical integration and R&D expenditure are positively correlated, suggesting that vertical integration can facilitate the transfer of technical information and also facilitate the implementation of new processes or the introduction of new products. However, higher levels of knowledge transfer are likely to discourage the firm to undertake own R&D efforts and therefore have a negative influence on producing new products (Ling Li *et al.*, 2010).

Apart from the above variables, profitability, embodied technology, disembodied technology, and industry concentration were also considered in the model. Profits are expected to have a positive influence on R&D efforts by generating internal funds. However, in the present study, profitability of the firms measuring retained earnings over net sales turnover does not appear to be a significant determinant of in-house R&D intensity. Similarly, even though it can be argued that a concentrated industry structure have a higher incentive to undertake R&D efforts in order to protect market position and create entry barriers, the present analysis does not find any significant impact of the HHI variable in influencing R&D intensity. Unlike the former empirical evidences in the Indian context, our empirical estimates of the import of capital goods and royalty and technical knowhow do not surface as statistically significant. Perhaps more reliance is laid on R&D spillovers in deciding whether to engage in in-house R&D efforts, and therefore these variables did not show any significant impact on firm's In-house R&D efforts.

7. Summary and Conclusion

This paper attempts to quantify the effects of R&D Spillovers on in-house R&D intensity for a sample of electronic firms in India. Using the CMIE Prowess database, we construct a measure for the potential pool of R&D Spillover and analyze the impact of this measure on firm's in-house R&D efforts. The theoretical literature has mostly followed the view that spillovers are substitutes, with public goods properties and that new information and knowledge is homogeneous across firms, irrespective of the industry's age and knowledge intensity (Harhoff, 2000). A positive effect of spillover on R&D intensity would suggest complementarity between external and internal R&D related knowledge. The empirical literature on the impact of spillovers remains inconclusive on their role and significance. In a regression equation relating the firm's patent count to its R&D expenditures and the relevant spillover pool variable, Jaffe (1986) finds that the coefficients of the spillover information a firm has access to and the coefficient on the interaction between a firm's own R&D and the spillover pool measure are positive and highly significant. On the other hand, Bernstein *et al.*, (1989) conclude that spillovers have a negative effect on the rate of investment and are actually capital-reducing, both for R&D and physical capital for the chemicals, instruments, machinery, and petroleum industry. Thus, the spillover effect depends upon the industry to which the firm belongs and the R&D capability of the firm.

Measures of spillover have been conceptualized either on the basis of the total stock of R&D of all "other" firms or on the basis of specific sources of spillovers like patent applications. Basant and Fikkert (1996) measure the domestic flow of spillovers by applying the inventory method to flows of R&D conducted by Indian firms in industry *j* at time *t* at the two digit level of industries belonging to the Manufacturing industry in India. In order to measure the international spillover variable, indices of relevance is constructed by considering the patent data in order to weight the R&D emanating from industry *j* in country *c*. Ray and Bhaduri (2001) examined the determinants of the R&D production function in the pharmaceuticals and electronics industry, and look at the participation of firms in R&D related national and international seminars and training programmes to capture the extent of benefits received by a firm from the common stock of available knowledge pool. In this paper, the R&D Spillover variable is defined as the aggregate of R&D expenditure of firms in related industry group normalized by their net sales at the five digit level of industries belonging to the Electronics Goods Sector in India. We apprehend that firms which are closely related in the sense of falling in the same industry group classification are presumed to benefit more from each other's R&D efforts than firms at a greater distance from each other.

Using Panel data estimation for the period 2002-2014, this paper finds that firms benefitting from R&D Spillovers in their line of business are spending less on in-house R&D activity. The results, however, suggest complementarity between in-house R&D efforts and R&D Spillovers for select industries within this sector. For instance, while complementarity exists between R&D Spillovers and in-house R&D efforts for Other Electronics[1] and Communication and Equipment industry group, the overall coefficient of R&D Spillovers is negative, suggesting substitutability when we consider the the entire Electronics goods sector together. Age of the firm, representing the learning by doing proposition, turned out with a positive and significant co-efficient. When R&D spillover is considered interacting with the age of the firm, we find that older firms that benefit from R&D Spillover appear to be less engaged in in-house R&D efforts. This result strongly supports the "absorptive capacity" hypothesis developed by Cohen and Levinthal (1989). The theory of "absorptive capacity" suggests an interaction between the firm's own knowledge stock built-up through firm's own prior R&D investments and the available spillover pool in the R&D spending regression. Further, small sized firms appear to be more R&D intensive than their larger counterparts, whereas vertically integrated firms are spending less on in-house R&D efforts. The paper highlights the possibilities of benefits appropriated by large and older firms from the available pool of R&D Spillovers. Small as well as young firms continue to rely on in-house R&D for their survival and growth. Also, the results clearly point out inter-industry differences, based on product lines, in technological efforts in the electronic goods sector in India.

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Appendix 1: The 12 industry groups constituting the sample used in the present study.

NIC Code	Industry Group	Product/Service Category
26101	Other Electronics	Capacitors, Electrolytic capacitors, Plastic film capacitors, Ceramic capacitors.
26102	Other Electronics	Crystals, Piezo electric elements Semiconductor devices, LCR bridges, LED lamps, Diodes, Diodes & transistors, Other display devices, integrated circuit, Quartz Crystals.
26109	Other Electronics	Heat sinks, Switches, Connectors, Filters, Servo components, Microwave passive components, Laminates, Moulding compounds in electronics, Coils, Magnetic media, Insulators in electronics, Floppy disks.
26209	Computers, Peripherals & Storage Devices	Computer peripherals, Data storage, memory systems.
26302	Communication Equipment	Communication & broadcasting equipment, Electronic telephones, Cordless phone, Transmission equipment, VHF radio systems, Electronic exchanges, Point to point / two way radio systems.
26309	Communication Equipment	Defence Communication Equipment.
26401	Consumer Electronics	TV picture tubes colour, Television receivers.
26405	Other Electronics	Electronic buzzers, Soft ferrites Soft ferrites, Amplifiers & PA systems.
26513	Miscellaneous Manufactured Articles	Meters electricity, Poly phase energy meters.
26517	Other Electronics	Control instrumentation & industrial electronics, Weighing system, load cell Control instrumentation & industrial electronics, Control panels, Sensors & indicators.
26519	Miscellaneous Manufactured Articles	Strategic electronics equipment, Scientific & laboratory instruments, Thermal analysis equipment, Industrial electronics & automation equipment, Electronic test & measuring instruments.
26600	Other Electronics	X-ray machine, Therapy equipment, Surgical equipment, Medical equipment, Surgical equipment, Pacemakers, Diagnostic equipment.